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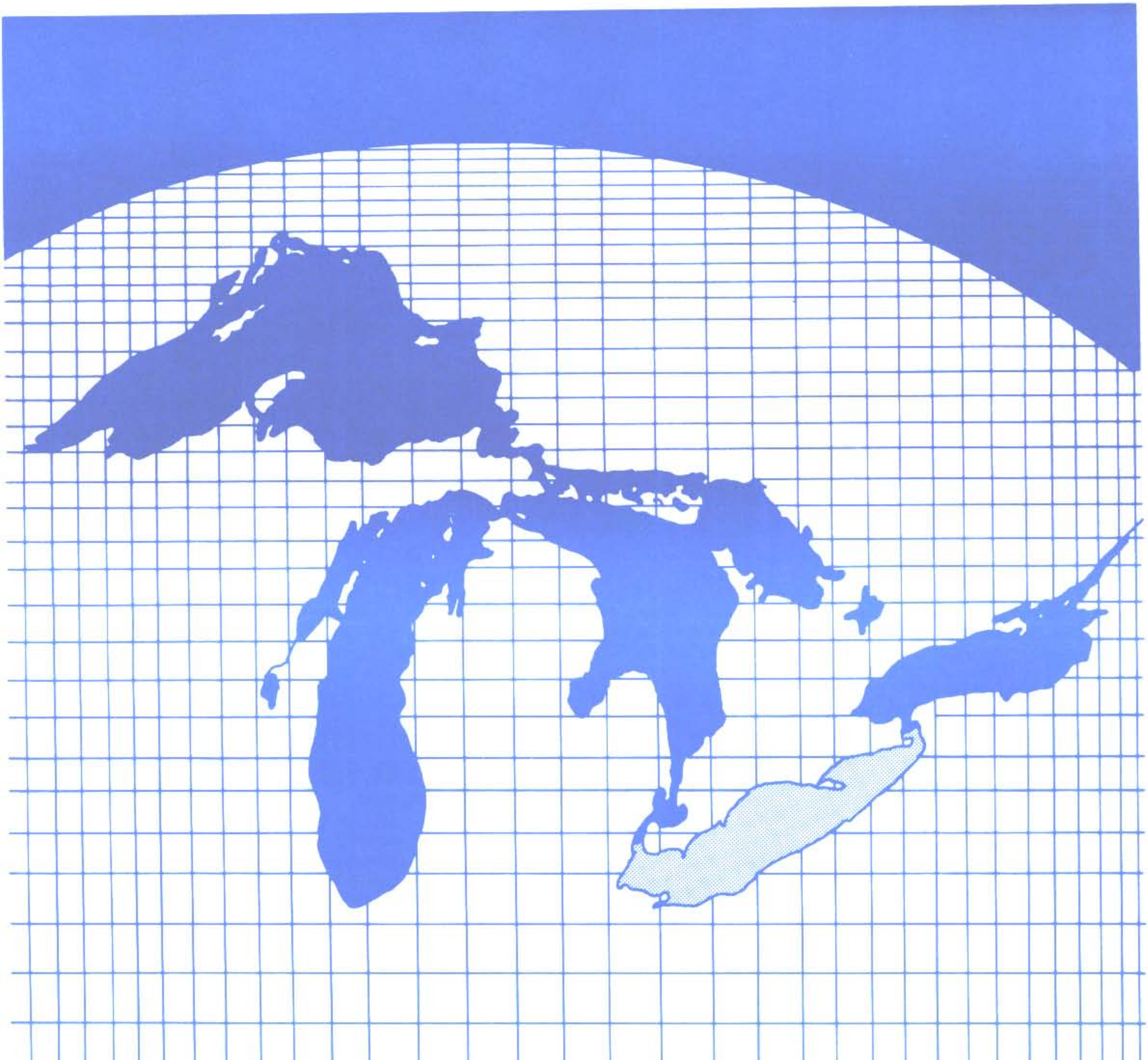
Lake Erie Water Quality 1970-1982: A Management Assessment



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Lake Erie Water Quality 1970-1982: A Management Assessment

by

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U.S. ENVIRONMENTAL PROTECTION AGENCY
536 SOUTH CLARK STREET
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PREFACE

Lake Erie has experienced several decades of accelerated eutrophication and toxic substances contamination. During the latter part of the 1960s remedial actions were planned and by the latter part of the 1970s, many of the plans were at least partially implemented. The first signs of lake recovery are now being observed through comprehensive monitoring programs. The intent of this report is to highlight the findings and conclusions of the 1978-1979 Lake Erie Intensive Study by placing them in perspective with earlier investigations and subsequent monitoring data from 1980 to 1982, where available. The primary purpose of this report is to provide management information in the form of a review of the lake's status and its trends <u>and</u> in the form of recommendations to ensure continued improvements in the quality of its waters and biota. For more detailed discussions of the methods, quality assurance procedures, and results of the study, the reader is referred to the final project report of the Lake Erie Technical Team, "Lake Erie Intensive Study 1978-1979 -- Final Report," edited by David E. Rathke.

I would like to acknowledge the excellent cooperation of the many investigators who participated in the Lake Erie Intensive Study and thank them for their contributions in the form of reports, data and helpful suggestions. I am particularly grateful for the assistance of Laura Fay, David Rathke, Gary Arico, Yu-Chang Wu, Cyndi Busic and Ginger-lyn Summer in the preparation of this report.

Charles E. Herdendorf, Chairman
Lake Erie Technical Assessment Team

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INTRODUCTION

Lake Erie, as one of the Great Lakes of North America, represents a significant source of fresh surface water for the people of Canada and the United States. In recognition of the importance of this resource and the need to restore and maintain its water quality, the Canadian and United States governments entered into the Great Lakes Water Quality Agreement in 1972. The Agreement was reaffirmed in 1978 and stipulated further actions to enhance water quality in the Great Lakes Basin ecosystem.

Both governments mandated the International Joint Commission (IJC) for the task of coordinating the implementation of the Agreement. Recognizing the need for a uniform surveillance effort by both parties of the agreements and the cooperating state and provincial jurisdictions, the IJC formed and directed the Water Quality Board to develop an international surveillance plan. Work groups were established for each lake, with the responsibility for developing detailed plans.

The Lake Erie Work Group prepared a nine-year surveillance plan in 1977, which was designed to provide an understanding of the overall, long-range responses of the lake to pollution abatement efforts. This plan was eventually incorporated as part of the Great Lakes International Surveillance Plan (GLISP) developed by the Surveillance Subcommittee of the Water Quality Board. The general objectives established for this plan included:

1. To search for, monitor, and quantify violations of the existing Agreement objectives (general and specific), the IJC recommended objectives, and jurisdictional standards, criteria and objectives. Quantification will be in terms of severity, areal or volume extent, frequency, and duration, and will include sources.

2. To monitor local and whole lake response to abatement measures and to identify emerging problems.

3. To determine the cause-effect relationship between water quality and inputs in order to develop appropriate remedial/preventative actions and predictions of the rate and extent of local/whole lake responses to alternative abatement proposals.

Within the context of these general objectives and considering the key issues specific to Lake Erie, the surveillance plan for Lake Erie additionally focused on:

1. Determining the long-term trophic state of the lake and to what degree remedial measures have affected improvements.

2. Assessing the presence, distribution, and impact of toxic substances.

3. Providing information to indicate the requirements for and direction of additional remedial programs, if necessary, to protect water uses.

The Lake Erie plan called for a two-year Intensive Study of main lake, nearshore and tributary conditions (1978 and 1979), followed by seven years of main lake monitoring (1980-1986), and then a repeat of the nine-year cycle. The overall objective of the Intensive Study was to provide information for a detailed assessment of inputs to the lake and the current condition of the lake. The intensive study was also designed to identify emerging problem areas, to detect changes in water quality on a broad geographic basis, and to provide information necessary for trend analyses. The study plan considered the seasonal nature of tributary inputs, lake circulation patterns, and nearshore-offshore gradients. The plan stressed linkages between the various components of the study in order to permit an adequate "whole lake" water quality assessment.

The following report highlights the findings and conclusions of the 1978-1979 Intensive Study. These results are placed in perspective with earlier investigations, particularly those since Project Hypo in 1970, and subsequent monitoring programs through 1982.

PHYSICAL CHARACTERISTICS OF LAKE ERIE

Basin Descriptions

Lake Erie is one of the largest lakes in the world, ranking thirteenth by area and eighteenth by volume (Herdendorf 1982). It is the southernmost of the Laurentian Great Lakes, lying between 41°21'N and 42°50'N latitude and 78°50'W and 83°30'W longitude. The lake is narrow and relatively shallow for a lake of its size (Figure 1), with its longitudinal axis oriented east-northeast. Lake Erie is approximately 388 km long and 92 km wide, with a mean depth of 19 m and a maximum sounding of 64 m. The lake has a surface area of 25,657 km^2, a volume of 484 km^3, a shoreline length of 1,380 km, and a surface elevation of 174 m above mean sea level.

Lake Erie can be naturally divided, on the basis of bathymetry, into three basins: western, central and eastern (Figure 2). The major morphometric dimensions of each basin and the entire lake are given in Table 1.

Western Basin. The western basin, lying west of a line from the tip of Pelee Point, Ontario, to Cedar Point, Ohio, is the smallest and the shallowest with most of the bottom at depths between 7 and 10 meters. In contrast with the other two basins, a number of bedrock islands and shoals are situated in the western basin and form a partial divide between it and the central basin. Topographically, the bottom is monotonously flat, except for the sharply rising islands and shoals in the central and eastern parts. The maximum depths in the basin are found in the interisland channels. The deepest sounding, 19 meters, was made in a small depression north of Starve Island Reef; south of Gull Island Shoal, in another depression, a depth of 16 meters has been recorded. Elsewhere in the basin these depths are not approached.

The waters of the western basin are more turbid than the other basins because of large sediment loads from the Detroit, Maumee and Portage rivers, wave resuspension of silts and clays from the bottom, and high algal productivity. The Detroit River accounts for over 90 percent of the flow of water into Lake Erie and therefore controls the circulation patterns in the western part of the basin. Its inflow

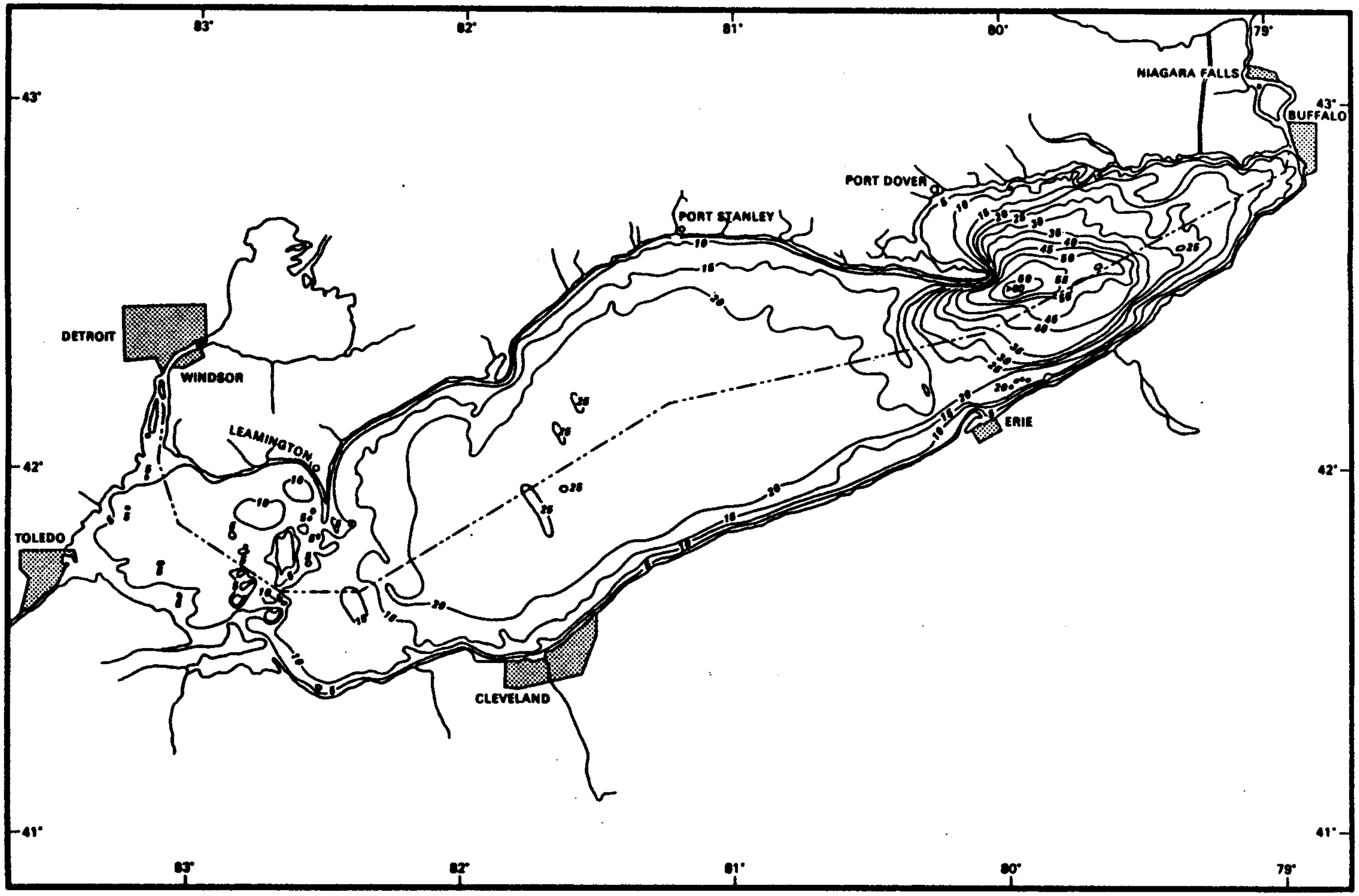


FIGURE 1. LAKE ERIE BATHYMETRY (depth in meters)

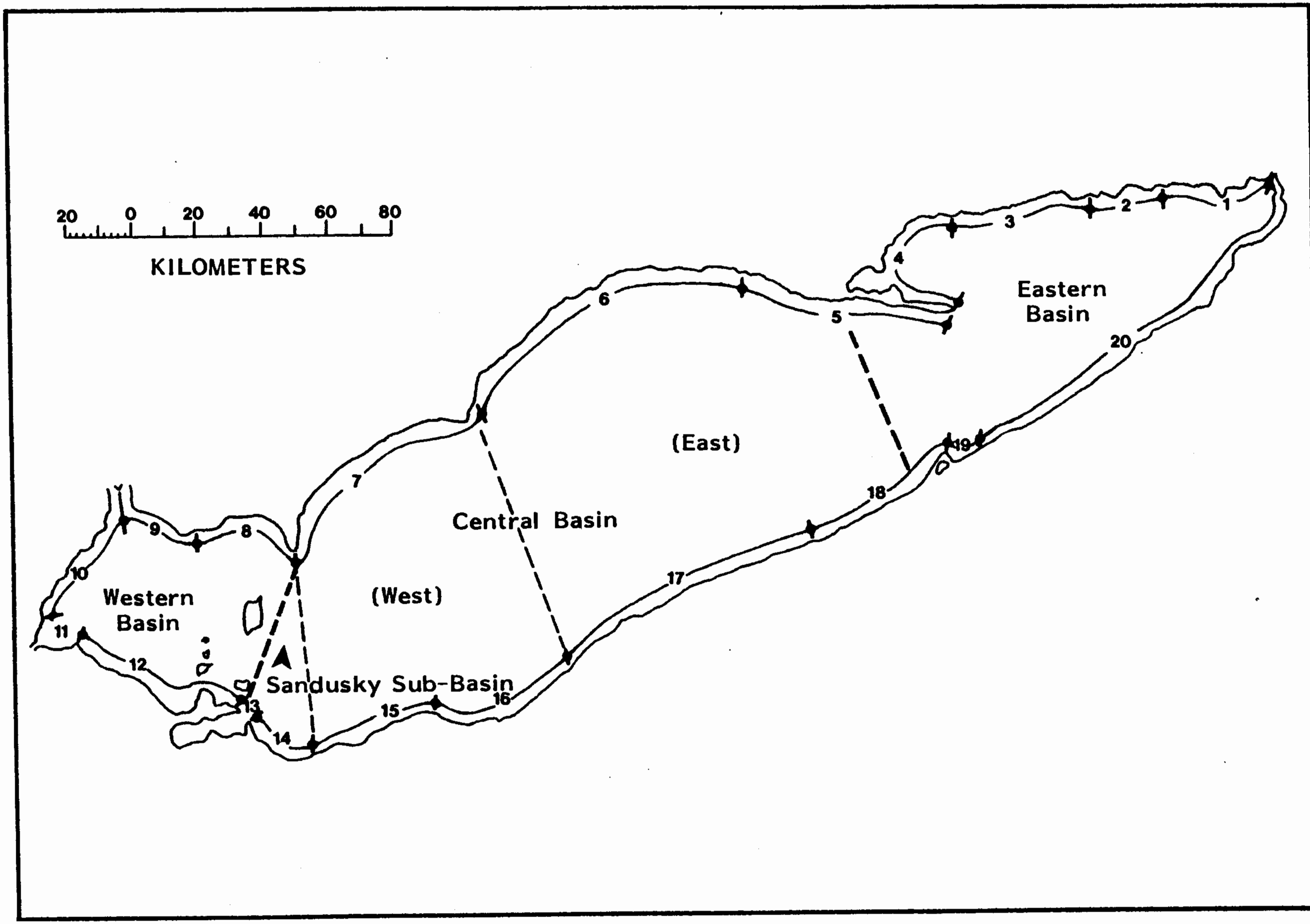


FIGURE 2. LAKE ERIE NEARSHORE REACHES AND MAIN LAKE BASINS

TABLE 1

MORPHOMETRY OF LAKE ERIE BASINS

Dimension	Western Basin	Central Basin	Eastern Basin	Entire Lake
Maximum Length (km)	80	212	186	388
Maximum Breadth (km)	64	92	76	92
Maximum Depth (m)	18.9	25.6	64.0	64.0
Mean Depth (m)	7.4	18.5	24.4	18.5
Area (km^2)	3,284	16,138	6,235	25,657
Volume (km^3)	25	305	154	484
Shoreline Length (km)	438	512	430	1,380
Percent of Area (%)	12.8	62.9	24.3	100
Percent of Volume (%)	5.1	63.0	31.9	100
Percent of Shoreline (%)	31.7	37.1	31.2	100
Development of Volume (ratio)	1.2	2.2	1.1	0.9
Development of Shoreline (ratio)	2.3	1.3	1.7	2.1
Water Storage Capacity (days)	51	635	322	1,008
Drainage Basin Land (km^2)	--	--	--	58,800
Mean Elevation (m)	--	--	--	173.86
Highest Monthly Mean Elevation (m)	--	--	--	174.58
Lowest Monthly Mean Elevation (m)	--	--	--	172.97
Mean Outflow (m/sec)	--	--	--	5,730
Highest Mean Monthly Outflow (m/sec)	--	--	--	7,190
Lowest Mean Monthly Outflow (m/sec)	--	--	--	3,280

penetrates far southward into the basin, retarding the dispersion of the sediment-laden Maumee River and the Michigan shore streams which results in high concentrations of contaminants along the western shore.

The water of the western basin is normally isothermal from top to bottom. Its shallowness precludes the formation of a permanent thermocline except in the deep holes. Occasionally during calm periods in the summer, the water stratifies thermally leading to rapid oxygen depletion near the lake bottom.

Central Basin. The central basin is divided from the western basin by the island chain and from the eastern basin by a relatively shallow sand and gravel bar between Erie, Pennsylania, and Long Point, Ontario. The central basin has an average depth of 19 meters and a maximum depth of 26 meters. Except for the rising slopes of a morainic bar extending south-southeastward from Pelee Point, Ontario, the bottom of the central basin is extremely flat. This bar forms a depression in the bottom between it and the islands, known as the Sandusky sub-basin (Figure 2). This sub-basin has an area of approximately 1,350 km^2 and a maximum depth of 16 m.

Although the central basin receives over 95 percent of its inflow from the western basin, the water is considerably less turbid and less biologically productive. Drainage from the western basin and inflow from the Sandusky River and other Ohio tributaries are concentrated in the Sandusky sub-basin and along the south shore where biological productivity and contaminants are the highest.

Water temperatures in the central basin are isothermal from fall to late spring; thermal stratification normally occurs below 15 meters from June until September. During the later part of the stratified period the thin hypolimnion may lose all of its dissolved oxygen.

Eastern Basin. The eastern basin is relatively deep and bowl-shaped. A considerable area lies below 35 meters and the deepest sounding, 64 meters, is found east-southeast of Long Point, Ontario. This basin is separated from the central basin by a glacially deposited bar which extends from the base of Long Point on the Ontario shore to Presque Isle at Erie, Pennsylvania. The bar contains a notch, known as the

Pennsylvania channel, which reaches a depth of over 20 meters and provides a subsurface connection for water circulation in both directions between the two basins.

The eastern basin receives over 95 percent of its water supply from the central basin, but in general it is less turbid and is the least biologically productive of all three basins. However, productivity is substantial along the south shore and near the mouth of the Grand River on the north shore.

The temperature structure of the eastern basin is similar to that of the deeper Great Lakes. It rarely freezes over (the western basin typically freezes over each winter and the central basin occasionally freezes from shore to shore), but it is often covered by drift ice from the other basins. The summer thermocline is thick, approximately 10 meters, and persists from early summer to November. The depth of the basin provides for a hypolimnion in excess of 40 meters in thickness. Although the dissolved oxygen content in the hypolimnion declines in the summer, it rarely drops below 50 percent of saturation.

Hydrology

Approximately 90 percent of the total inflow to Lake Erie comes from the Detroit River, the drainage outlet for Lake Huron. The average annual inflow a measured by the U.S. Lake Survey near the head of the Detroit River is 5,150 m^2/sec, equivalent to 6.4 meters of water covering Lake Erie. Surface runoff from the drainage area enters the lake via many smaller tributary rivers or by direct runoff from the shore areas. Average annual runoff is estimated at 580 m^3/sec, equivalent to 0.7 meters of water over the lake's surface. The outflow from Lake Erie is through the Niagara River at Buffalo and the Welland Canal diversion at Port Colborne. Combined outflow averages about 5,730 m^2/sec annually, equivalent to 7.1 meters of water over Lake Erie.

The average annual rainfall in the Lake Erie Basin is about 90 cm and ranges between 80 and 93 cm. The total land area which drains into Lake Erie, excluding that above the mouth of the Detroit River, is only about three times the area of the water surface of the lake. The large expanse of water affords a great opportunity for evaporation, and the amount of water which has been lost is estimated to be between

85 and 91 cm. This amount of evaporation is approximately equivalent to the average annual rainfall over the lake. During dry periods more water may be evaporated from the lake than flows into it from all of its tributaries. Under these conditions Lake Erie delivers into the Niagara River a smaller quantity of water than it receives from the Detroit River.

Circulation

Water movement in the western basin of Lake Erie is strongly influenced by Detroit River flow. This inflow is composed of three distinct water masses. The midchannel flow predominates and is characterized by 1) lower temperature, 2) lower specific conductance, 3) greener color and higher transparency, 4) lower phosphorus concentration, 5) higher dissolved-oxygen content, 6) lower chloride-ion concentration, and 7) lower turbidity than the flows on the east and west sides of the river. The midchannel flow penetrates deeply into the western basin where it mixes with other masses and eventually flows into the central basin through Pelee Passage and to a lesser extent through South Passage. The side flows generally cling to the shoreline and recycle in large eddy currents.

In the central basin, the prevailing southwest winds are parallel to the longitudinal axis of the lake. Because of the earth's rotation these winds generate currents which cause a geostrophic transport of water toward the United States shore. This convergence of water on the south shore results in a rise in lake level which is equalized by sinking of water along this shore. At the same time the lake level is lowered along the Canadian shore as surface currents move the water offshore. The sinking along the south shore appears to be compensated by a subsurface movement of water toward the north and an upwelling along the Ontario shore.

The thermocline is approximately 10 meters shallower adjacent to the north shore than on the south side of the lake; this can be interpreted as an upwelling influenced by the prevailing southwest winds (Herdendorf 1970). The resultant surface currents indicate a net eastward movement, while subsurface readings show a slight net westward movement. This can be explained by the cycle of 1) surface transport of water toward the southeast, 2) sinking of water off the south shore, 3) subsurface transport toward the north-northwest, and 4) upwelling adjacent to the north shore.

The pattern of this type of circulation would be analogous to coils of a spring that tapers toward the eastern end of the lake.

The formation of a deep thermocline in the southern half of the central basin results in a relatively thin hypolimnion which is highly susceptible to oxygen depletion by sediments with high oxygen demands. These circumstances result in the presence of anoxic bottom water particularly in the southwestern part of the basin.

The bottom deposits of the northern part of the central basin are predominantly glacial till and do not have the high oxygen demands of the clay muds in the southern half of the basin. This fact, coupled with a thicker hypolimnion off the northern shore and entrainment of eastern basin water flowing westward through the Pennsylvania channel, apparently accounts for the more abundant dissolved oxygen at the bottom.

In the eastern basin the thermocline over the "deep hole" commonly forms at a depth of 14 meters, allowing a considerably thicker hypolimnion (40 meters) than in the central basin. In general, midlake water in the central and eastern basins of Lake Erie, lakeward of a narrow band of shore-influenced water, is relatively uniform in quality. Some variation in the concentration of dissolved substances occurs between the epilimnion and hypolimnion waters in these basins and is probably caused by the high oxygen demand and the regeneration of nutrients from the sediments. Most dissolved solids showed a marked increase from Lake St. Clair to the Niagara River as they pass through Lake Erie.

Organization of Data Collection and Analysis

Field investigations for the Intensive Study were initiated in January 1978 under the auspices of the IJC. Approximately 25 organizations collected data relevant to the effort (Table 2). Most components of the plan were implemented on schedule as the environmental protection, natural resource management, and scientific research communities of the Great Lakes region embarked on the two-year study (Table 3). Planning and implementation of the study was coordinated by the Lake Erie Work Group of the Surveillance Subcommittee. This subcommittee served the Implementation Committee of the IJC Great Lakes Water Quality Board. The Lake Erie Work Group was charged with the responsibility of monitoring the progress of field investigations and preparation of reports which analyze the results of these studies, and the production of a comprehensive assessment of the current status of Lake Erie.

The methods for data collection and sample analysis are outlined in the Lake Erie Surveillance Plan prepared by the Lake Erie Work Group (Winklhofer 1978). Specific methods employed for the Intensive Study are contained in the numerous reports submitted by study participants (Appendix A, B and C). Of major importance were the methods used for the main lake and nearshore components; since six organizations were responsible for these components encompassing the entire water mass of the lake, data compatability was essential:

Main Lake

1. USEPA, Great Lakes National Program Office (USEPA/GLNPO)

2. National Water Research Institute, Canada Centre for Inland Water (NWRI/CCIW)

TABLE 2

ORGANIZATIONS PARTICIPATING IN THE LAKE ERIE INTENSIVE STUDY

AGENCY OR ORGANIZATION	RESPONSIBILITY
Canada-Federal	
1. National Water Resources Institute, Canada Centre for Inland Waters (NWRI/CCIW)	Central Lake Erie oxygen study; water circulation study; atmospheric inputs
2. Department of Fisheries and Oceans (DF&O)	Wildlife contaminants study
Canada-Provincial	
3. Ontario Ministry of the Environment (OME)	Tributary inputs; point source inputs; water intakes; beach surveys
4. Ontario Ministry of Natural Resources (MNR)	Fish contamination surveys; fish stock assessment
United States-Federal	
5. National Aeronautical and Space Administration, Lewis Research Center (NASA)	Remote sensing images of suspended sediment and chlorophyll biomass; ice conditions; surface temperature
6. National Oceanic and Atmospheric Administration Great Lakes Environmental Laboratory (NOAA/GLERL)	Water levels and flows; current meter survey/circulation patterns; nutrient models

TABLE 2 (CONTINUED)

	AGENCY OR ORGANIZATION	RESPONSIBILITY
7.	U.S. Army, Corps of Engineers Buffalo District (USACOE)	Wastewater management study; loading calculations for tributaries and connecting channels
8.	U.S. Environmental Protection Agency Great Lakes National Program (USEPA/GLNPO)	Main Lake Erie monitoring, Western, Central and Eastern basins; TAT planning
9.	U.S. Environmental Protection Agency Large Lakes Research Station (USEPA/LLRS)	Oxygen and nutrient models; fish contaminants; Cladophora surveys
10.	U.S. Environmental Protection Agency Region V, Eastern District Office (USEPA/ED)	Logistical support; point source inputs; TAT planning
11.	U.S. Fish and Wildlife Service (USF&WS)	Fish contamination surveys; fish stock assessment
12.	U.S. Geological Survey (USGS)	Tributary stream gauging, flows and water quality
	United States-State and County	
13.	Erie County (PA) Department of Health (ECDH)	Tributary inputs; point source inputs; water intakes; beach surveys
14.	Michigan Department of Natural Resources (MDNR)	Tributary inputs; point source inputs; water intakes; beach surveys; Detroit River discharge

TABLE 2 (CONTINUED)

AGENCY OR ORGANIZATION	RESPONSIBILITY
15. New York State Department of Environmental Conservation (NYDEC)	Tributary inputs; point source inputs; Niagara River discharge
16. New York State Department of Health (NYDH)	Beach surveys; water intakes
17. Ohio Department of Natural Resources (ODNR)	Fish stock assessment, fish kill investigations
18. Ohio Environmental Protection Agency (OEPA)	Tributary inputs; point source inputs; water intakes; beach surveys
United States-Municipal	
19. City of Cleveland Water Quality Laboratory (CWQL)	Harbor monitoring for water quality
20. City of Toledo, Pollution Control Agency (TPCA)	Harbor monitoring for water quality
United States-University	
21. Heidelberg College (HC)	Central Lake Erie nearshore
22. Ohio State University, Center for Lake Erie Area Research (OSU/CLEAR)	Western Lake Erie nearshore; Central basin oxygen depletion rates; *Cladophora* surveys; fish contamination survey at tributary mouths

TABLE 2 (CONTINUED)

	AGENCY OR ORGANIZATION	RESPONSIBILITY
23.	State University College of New York at Buffalo, Great Lakes Laboratory (SUNY/GLL)	Eastern Lake Erie nearshore; *Cladophora* surveys
24.	University of Toledo (UT)	Limnological study of Maumee River and Bay
International		
25.	International Joint Commission (IJC)	Quality control/assurance for measurement; statistical procedures; logistical support for meetings and report preparation; final report printing and distribution

TABLE 3

MAJOR COMPONENTS OF THE LAKE ERIE INTENSIVE STUDY

TOPIC	ORGANIZATION RESPONSIBLE
<u>Main Lake</u>	
Main Lake Monitoring Report	USEPA/OSU/CLEAR
Oxygen Studies	NWRI/CCIW
Sedimentation/Carbon Flux	NWRI/CCIW
Sediment Oxygen Demand	USEPA/LLRS
Lake Response to Nutrient Loading	USEPA/LLRS
Lake Circulation	NOAA/GLERL
Lake Physics Studies:	NWRI/CCIW
Interbasin transfer	
Nearshore-offshore movement	
Vertical drift	
<u>Nearshore</u>	
Canadian Nearshore	OME
Western Basin, U.S.	OSU/CLEAR
Central Basin, U.S.	HC
Eastern Basin, U.S.	SUNY/GLL
Cladophora	SUNY/GLL
Cleveland Intakes	CWQL
Toledo/Maumee Estuary	TPCA
<u>Input and Problem Areas</u>	
NY Beaches, Tributaries, Intakes and Pt. Sources	NYDEC
PA Beaches, Tributaries, Intakes and Pt. Sources	ECDH
OH Beaches, Tributaries, Intakes and Pt. Sources	OEPA
MI Beaches, Tributaries, Intakes, Point Sources, and Detroit River	MDNR
ONT Beaches, Tributaries, Intakes, Point Sources, and Niagara River	OME
Tributary, Point Sources, and Atmospheric Loading	IJC
Meteorological/Hydrological Summary	NOAA/GLERL
<u>Contaminants</u>	
Radioactivity	IJC
Fish Contaminants	USEPA/USF&WS
Wildlife Contaminants	DF&O

TABLE 3 (CONTINUED)

TOPIC	ORGANIZATION RESPONSIBLE
<u>Data Quality</u>	
Data Quality Report	IJC
Data Management Report	IJC
Field and Laboratory Procedures	IJC
<u>Special Contributions</u>	
Fish Stock Assessment	GLFC
Remote Sensing Experiments	NASA
Wastewater Management Study	USACOE
Tributary and Storm Event Reports	USGS
Phosphorus Management Study	IJC
Primary Productivity Study	NWRI/CCIW OSU/CLEAR

Nearshore

1. Ohio State University, Center for Lake Erie Area Research (OSU/CLEAR) - western Lake Erie, Detroit River to Huron, Ohio

2. Heidelberg College (HC) - central Lake Erie, Vermilion, Ohio to Ashtabula, Ohio

3. State University of New York College at Buffalo, Great Lakes Laboratory (SUNY/GLL) - eastern Lake Erie, Conneaut, Ohio to Buffalo, New York

4. Ontario Ministry of Environment, Water Resources Branch (OME) - western Lake Erie, Detroit River to Point Pelee, central Lake Erie, Point Pelee to Long Point, and eastern Lake Erie, Long Point to Niagara River

The parameters and typical methods used for water, biological, and sediment measurements are listed in Table 4. To facilitate problem area assessment and the determination of long-term trends, emphasis was placed on those parameters subject to non-compliance with the Water Quality Agreement and/or jurisdictional criteria, standards, or guidelines. For purposes of the Intensive Study, the lake was divided into a series of main lake compartments and nearshore reaches (Figure 2) with a combined station pattern totalling over 500 stations (Figure 3). Cruises were scheduled to provide a reasonably synoptic view of the entire lake (Figure 4). Data from these cruises constitute the foundation for the whole lake assessment.

In order to assist the Lake Erie Work Group in meeting its responsibility to bring the general objective of the Intensive Study to fruition, the Center for Lake Erie Area Research (CLEAR) proposed the creation of a technical assessment team with scientific and technical knowledge of Lake Erie and report editing, research project administration, and data management skills. In March 1980, at the conclusion of the Intensive Study field investigations, such a team was established at The Ohio State University by a grant from the U.S. Environmental Protection Agency, Great Lakes National Program Office.

TABLE 4

PARAMETERS MEASURED FOR THE LAKE ERIE INTENSIVE STUDY

Water Parameters

1. Temperature
2. Wind speed and direction
3. Transparency, Secchi Disk (20 cm)
4. Wave height
5. Extinction depth
6. Aesthetics
7. Turbidity
8. Suspended solids
9. Dissolved oxygen
10. pH
11. Specific conductance
12. Alkalinity
13. Total phosphorus
14. Total dissolved phosphorus
15. Soluble reactive phosphorus
16. Total kjeldahl nitrogen
17. Ammonia
18. Nitrate & Nitrite N
19. Dissolved reactive silicate
20. Chloride
21. Sulfate
22. Calcium
23. Magensium
24. Sodium
25. Potassium
26. Aluminum, total
27. Aluminum, dissolved
28. Cadmium, total
29. Cadmium, dissolved
30. Chromium, total
31. Chromium, dissolved
32. Copper, total
33. Copper, dissolved
34. Iron, total
35. Iron, dissolved
36. Lead, total
37. Lead, dissolved
38. Manganese, total
39. Manganese, dissolved
40. Nickel, total

Biological Parameters

1. Phytoplankton
2. Zooplankton
3. Chlorophyll a
4. Pheophytin
5. Aerobic heterotrophs
6. Fecal coliforms
7. Fecal streptococci
8. Benthos

Sediment Parameters

1. Solids, total
2. Solids, volatile
3. Chemical oxygen demand
4. Total organic carbon
5. Total phosphorus
6. Total kjeldahl nitrogen
7. Ammonia nitrogen
8. Arsenic
9. Selenium
10. Cadmium
11. Chromium
12. Copper
13. Iron
14. Lead
15. Nickel
16. Silver
17. Zinc
18. Mercury
19. Cyanide
20. PCBs, total
21. Hexachlorobenzene
22. beta-Benzenehexachloride
23. Lindane
24. Treflan
25. Aldrin
26. Isodrin
27. Heptachlor epoxide
28. Chlordane
29. DDT and metabolites
30. Methoxychlor

TABLE 4 (CONTINUED)

Water Parameters	Sediment Parameters
41. Nickel, dissolved	31. Mirex
42. Vanadium, total	32. 2,4-D Isopropyl Ester
43. Vanadium, dissolved	33. Endosulfan I
44. Zinc, total	34. Endosulfan II
45. Zinc, dissolved	35. Dieldrin
46. Arsenic, total	36. Endrin
47. Mercury, total	37. Tetradifon
48. Selenium, total	38. Grain-size analysis
49. Silver, total	
50. Silver, dissolved	
51. Cyanide	
52. Phenol	
53. Total organic carbon	
54. Dissolved organic carbon	

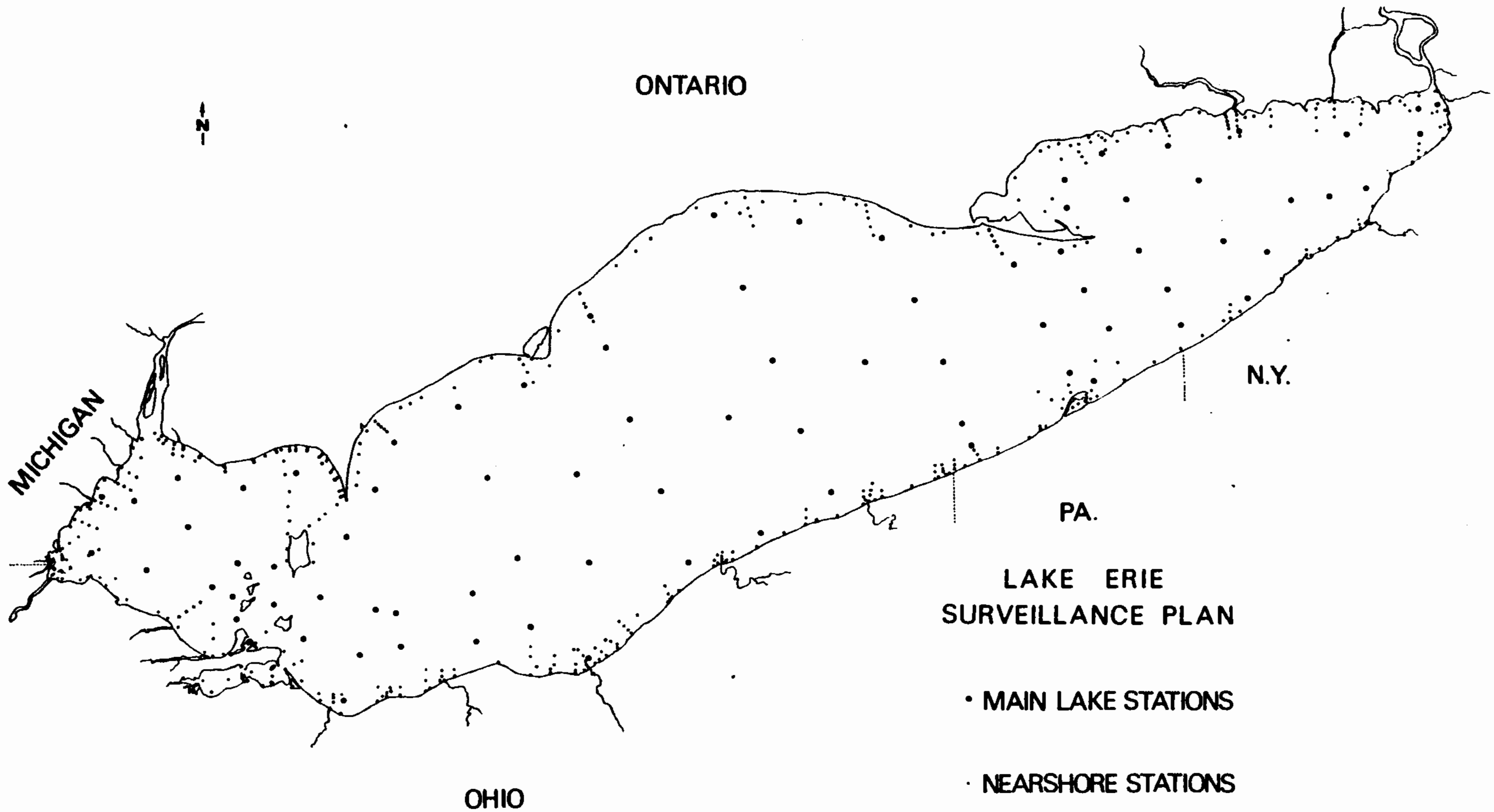


FIGURE 3. LAKE ERIE INTENSIVE STUDY STATION PLAN

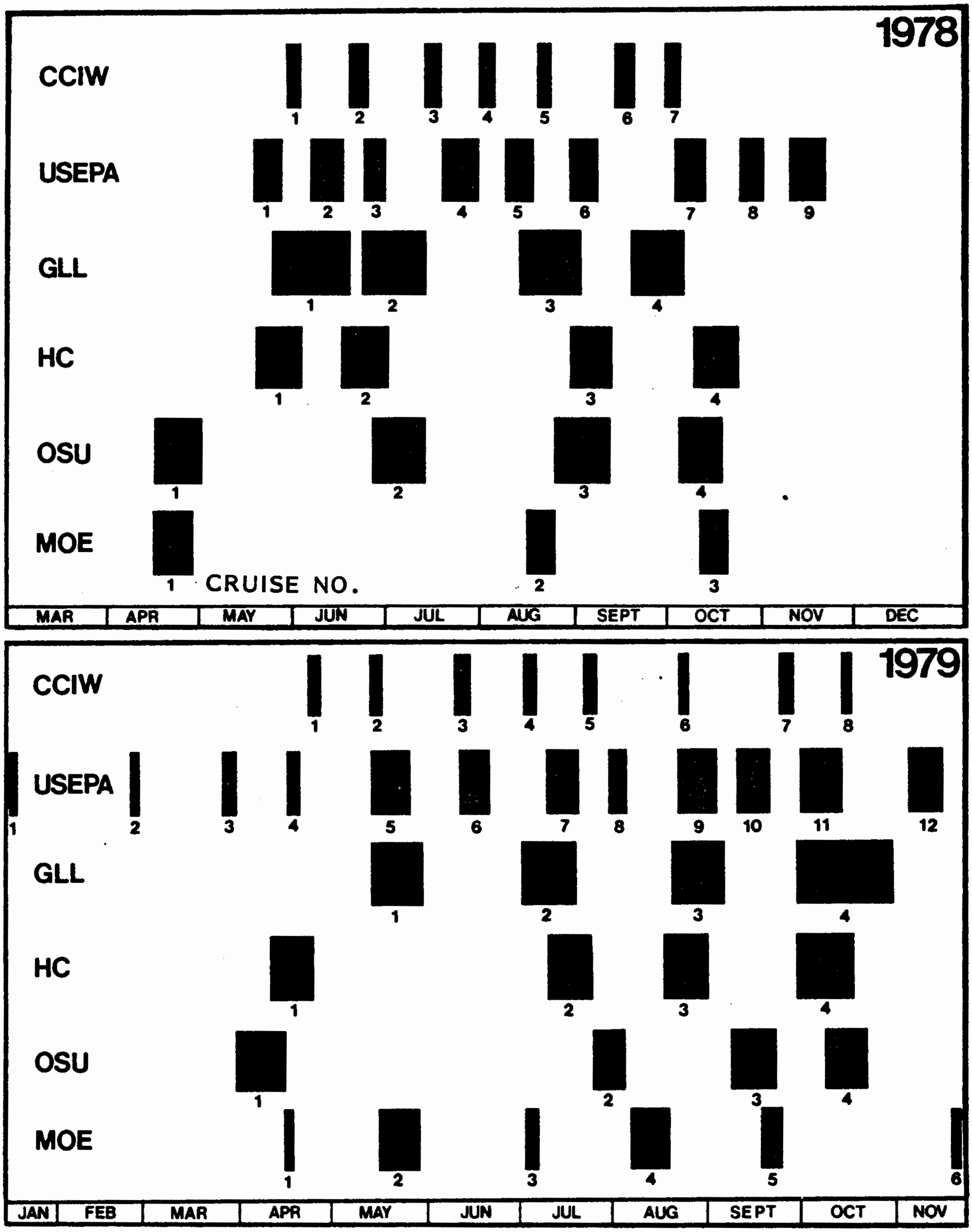


FIGURE 4. LAKE ERIE INTENSIVE STUDY CRUISE SCHEDULE

The Lake Erie Technical Assessment Team (TAT) was thus formed to synthesize data from the diverse groups into a unified whole lake assessment. TAT functioned to provide a scientific focus for coordination and cooperation, for promotion of information exchange, and for creation of an atmosphere in which a consensus could be reached on technical matters. Specific objectives of TAT included:

1. To provide professional supervision and a pool of scientific and technical skills to supplement the international scientific staff involved in the intensive study.

2. To coordinate and guide, essentially on a daily basis, efforts of the various contributing scientists.

3. To exercise technical review and editorial responsibilities for the individual reports.

4. To perform an in-depth and integrated analysis of the data base for the purpose of a comprehensive assessment.

5. To assure that all pertinent baseline data resulting from Canadian and United States sources are entered in STORET for the purpose of this assessment and future analysis.

6. To exercise the aforementioned functions towards aggregating all Canadian and United States elements of the intensive study to produce a timely, unified whole lake report which will:

    a. determine the status of the open water and nearshore areas of Lake Erie in terms of

        1) trophic level,
        2) toxic substances burden,
        3) pathogenic bacteria contamination,
        4) suspended materials load, and
        5) oxygen demand;

b. provide baseline data for the chemical, microbiological, and physical parameters of water quality against which future changes may be judged;

c. compare the present data with past data in order to determine how rapidly and in what manner the lake is changing;

d. determine how these changes are related to waste reduction, pollutant bans, nutrient control programs, and pollution abatement programs; and

e. prepare recommendations concerning the scope of future remedial programs to enhance or maintain current lake water quality.

Technical Assessment Team Participants

The Lake Erie TAT consisted of a technical staff headquartered at The Ohio State University and a select group of Canadian and United States scientists who contributed data, technical reports and guidance to the effort. The individuals listed below participated in the assessment undertaken by the Lake Erie TAT:

Technical Staff

1. Charles E. Herdendorf, Chairman
2. C. Lawrence Cooper, Coordinator
3. David E. Rathke, Editor
4. Laura A. Fay
5. John J. Mizera
6. Mark D. Barnes
7. R. Peter Richards
8. Gary Arico

Contributors

1. Carl Baker - Ohio Department of Natural Resources
2. David Baker - Heidelberg College
3. Robert Bowden - USEPA, Great Lakes National Program

4. Farrell Boyce - Canada Centre for Inland Waters
5. Noel Burns - Canada Centre for Inland Waters
6. Murray Charlton - Canada Centre for Inland Waters
7. James Clark, USEPA, Great Lakes National Program
8. John Clark - International Joint Commission, GLRO
9. David DeVault - USEPA, Great Lakes National Program
10. Clay Edwards - International Joint Commission, GLRO
11. Andrew Fraser - Canada Centre for Inland Waters
12. V. Ray Fredrick - SUNY, Great Lakes Laboratory
13. Douglas Haffner - International Joint Commission, GLRO
14. Douglas Hallett - Canada Wildlife Service
15. Yousry Hamdy - Ontario Ministry of the Environment
16. David Rockwell - USEPA, Great Lakes National Program
17. Fernando Rosa - Canada Centre for Inland Waters
18. Robert Sweeney - SUNY, Great Lakes Laboratory
19. Nelson Thomas - USEPA, Large Lakes Research Station
20. Richard Thomas - Department of Fisheries and Oceans, Canada Centre for Inland Waters
21. Joseph Vihtelic - Michigan Department of Natural Resources
22. Lester Walters - Bowling Green State University
23. Robert Wellington - Erie County Department of Health, Pennsylvania
24. Richard Winklhofer - USEPA, Region V, Eastern District
25. Stanley Witt - USEPA, Great Lakes National Program
26. Stephen Yaksich - U.S. Army Corps of Engineers, Buffalo District

Appendix A lists the reports prepared by the Lake Erie Technical Assessment Team, Appendix B lists reports contributed to the Lake Erie Intensive Study by other investigators, and Appendix C lists the basic documents used by TAT to prepare this report.

Study Limitations

Implementation of study plan. The study plan developed by the Lake Erie Work Group was implemented in most details and on schedule. Notable exceptions to complete implementation included:

1. Atmospheric loadings were not determined during the study period.

2. United States nearshore surveys were conducted for three consecutive days rather than five consecutive days specified in the plan.

3. Canadian nearshore surveys were not comprehensive for the entire shore, but localized in problem areas due to the availability of comprehensive data from earlier studies.

4. Soluble nutrients were not included in the eastern United States nearshore cruises.

5. Electronic bathythermograph (EBT) recordings for depth greater than 10 meters were not included in central United States nearshore cruises.

6. Samples for benthos and toxic organic compounds in main lake sediments were not obtained.

7. Radiological data was not collected, except in the vicinity of the Davis-Besse Nuclear Power Station near Port Clinton, Ohio.

Data gaps. In addition to the loss of data due to incomplete implementation of the plan, the following problems encountered during the field investiation and analysis phases of the study resulted in further loss of anticipated data:

1. Fish studies of the nearshore are only partially completed.

2. Metal analysis from both main lake and nearshore studies suffered from problems in analysis, as did analysis for toxic organics in nearshore water, sediment and fish samples.

3. Water intake data are incomplete for toxic organic compounds.

4. Fewer zooplankton samples were collected and analyzed than planned.

5. Some phosphorus data for 1978 from the main lake stations demonstrated a low bias.

6. Detection limits insufficient to meet IJC objectives for some parameters resulted in excess violations to be reported.

7. In some cases, reports on individual studies (secondary components) were not prepared; however data are usually available.

Data compatability. Analysis of study results from the participating laboratories shows that the comparability of data is not seriously affected by differences in precision, except for dissolved and total metals which are present in the lake water at very low concentrations. However, differences resulting from individual laboratory biases are significant for several parameters, particularly phosphorus, when compared to the temporal and spatial variability observed in the lake. Therefore, it is not possible (in all cases) to assume complete compatibility of data gathered by different agencies, or by the same agency in different years. The question of data comparability is a relative one, and judgments about the use of combined of data sets must ultimately be made in the context of the specific questions to which the data are to be applied. Certainly the data gathered for the Intensive Study can be used to compare various portions of the lake, to define the lake's overall status and, for many parameters, to specify violations of water quality objectives. However, the utility of combined data sets to establish long-term trends is less certain.

A test of data compatibility was performed in the western basin by pooling nearshore and offshore data gathered by CLEAR, OME and USEPA. Using SYMAP plots of nine individual parameters, contoured distribution maps were constructed for seven cruises (see Figures 24 and 37 for examples of SYMAP plots). These maps showed expected nearshore/offshore gradients and northshore/southshore differences with the absence of dicontinuities at agency interfaces. Experiments such as this add credibility to the lake-wide assessment attempted by this study.

CONCLUSIONS

The major issues considered by the Intensive Study can be categorized into five topics: 1) lake enrichment, 2) toxic substances, 3) public health, 4) land use activities and 5) lake response to remedial actions. In order to place the time period of the Intensive Study (1978-1979) into perspective, results are presented in reference to previous investigations and to those conducted since the end of the Intensive Study.

Lake Enrichment

Prior to 1970, water quality investigations of Lake Erie were conducted at sporadic intervals with a wide variety of field procedures and analytical techniques. For these reasons it is difficult to document long-term trends to any degree of accuracy. Starting with Project Hypo (Burns and Ross 1972) in 1970 (a joint Canadian-United States project to investigate the eutrophication of Lake Erie), consistent shipboard and laboratory procedures have been utilized by the several research groups monitoring the status of the open waters of Lake Erie. For the past decade, cruises have been undertaken annually in the three basins of the lake by the following organizations: 1) Canada Centre for Inland Waters (NWRI), 2) Center for Lake Erie Area Research (OSU), 3) Great Lakes Laboratory (SUNY) and 4) Great Lakes National Program Office (USEPA). The following discussion characterizes the conditions of the lake for several eutrophication-related parameters during the period 1970 to 1982.

Lake levels. The mean Lake Erie water level for the period 1860 to 1970 was 570.37 feet above International Great Lakes Datum, 1955. For the period 1960 to 1970, the average level was 570.24 feet, only slightly below the mean. However, for the period 1970 to 1980, the average level rose to 571.74, a volumetric increase of approximately 3% between the two decades. Of significance to water quality, lake levels during the period 1970 to 1980 averaged about 0.5 m above levels for the preceeding decade. The lowest annual water level (569.01 feet for 1964) within the earlier decade was about 1.1 m below the mean level for the highest year (572.72 for 1973) of the latter decade. This change amounts to about a 7% increase in lake volume.

Higher lake levels have primarily resulted from an increased flow of higher quality water from the upper Great Lakes via the Detroit River. This dilution effect, in combination with more deeply submerged substrates in the nearshore regions and western basin shoals, may have had profound impacts on the lake biota. With higher water, greater attenuation of light reaching substrate suitable for the development of both planktonic and attached forms of algae has occurred. Lake level changes have likely contributed to the absence, in the mid-1970s, of the basin-wide algal blooms and massive growths of the filamentous algae, Cladophora glomerata, which were so prevalent in the mid-1960s.

Thermal structure. The western basin of Lake Erie is essentially isothermal throughout the year. This basin was determined to be unstratified during all 80 cruises undertaken during the period 1970-1982. However, periods of temporary stratification in isolated areas of the western basin have been reported by Britt (1955), Carr et al. (1965) and Zapotosky and Herdendorf (1980). Such stratification is usually transitory in nature but can result in severe oxygen depletion conditions due to high oxygen demand of the sediments.

The central basin of Lake Erie typically stratifies into three layers (referred to as limnions in this report) in early June and turns over in early September. The mean thicknesses of the epilimnion, mesolimnion and hypolimnion during the period 1970-1982 are presented in Table 5 and summarized below:

Central Lake Erie Thermal Strata

Limnion	Thickness (m) ($\pm$ std error)	Cruises (N)
Epilimnion	13.2 ± 0.4	42
Mesolimnion	2.1 ± 0.2	42
Hypolimnion	4.5 ± 0.3	47

The area of the central basin hypolimnion averages approximately 11,300 km^2 (Table 6) or about 70% of the surface area of the entire basin. The mean thickness of the

TABLE 5

LAKE ERIE CENTRAL BASIN THERMAL STRUCTURE
(Thickness of Limnions in Meters)

	1970	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	Mean	Std Error (+)
MAY													
Epi							5.7	11.8			12.6	10.0	2.2
Meso							6.5	2.9			3.3	4.2	2.4
Hypo	3.0						8.6	5.6			5.7	5.7	2.7
Total							20.8	20.3			21.6	19.9	
JUNE													
Epi			11.2	9.2	11.2	9.5	10.9	15.5	14.7	10.8	15.4	12.0	0.8
Meso			1.6	2.1	1.2	2.7	4.5	1.9	1.6	1.8	1.5	2.1	0.7
Hypo	3.9		6.2	7.7	6.6	6.8	4.7	3.3	7.3	7.4	3.9	5.8	1.8
Total			19.0	19.0	19.0	19.0	20.1	20.7	23.6	20.0	20.8	19.9	
JULY													
Epi		12.5	13.8	9.8		12.4	11.7	14.3	12.7	12.7	12.7	12.5	0.4
Meso		1.7	1.1	2.4		2.0	4.0	2.4	1.7	2.4	3.0	2.3	0.3
Hypo	3.1	5.0	4.6	6.7		4.6	4.8	4.4	6.2	5.2	4.7	4.9	0.3
Total		19.2	19.5	18.9		19.0	20.5	21.1	20.6	20.3	20.4	19.7	
AUGUST													
Epi		12.3	12.6	10.5	14.0	15.0	13.5	13.4	13.3	14.9	15.4	13.5	0.5
Meso		2.0	1.4	1.6	2.0	1.0	2.6	2.2	2.1	1.7	1.0	1.8	0.2
Hypo	2.7	4.4	4.3	6.8	3.0	3.0	4.1	4.4	5.8	4.3	4.0	4.3	0.4
Total		18.7	18.3	18.9	19.0	19.0	20.2	21.0	21.2	20.9	20.4	19.6	
SEPTEMBER													
Epi		13.0	12.6		14.4	15.7	16.3	16.7	13.5	17.5	17.2	15.2	0.6
Meso		2.0	1.8		2.6	1.2	1.8	1.5	1.6	1.3	1.9	1.7	0.3
Hypo	1.8	3.0	4.6		2.0	2.1	3.4	2.7	5.2	3.0	2.6	3.0	0.4
Total		18.0	19.0		19.0	19.0	21.5	20.9	20.3	21.8	21.7	19.9	
LATE SEPT													
Epi		14.4					17.1					15.8	1.4
Meso		1.5					1.8					1.6	0.2
Hypo		2.1					2.7					2.4	0.3
Total		18.0					21.6					19.8	

TABLE 6

LAKE ERIE CENTRAL BASIN HYPOLIMNION AREA

Year	May (km^2)	June (km^2)	July (km^2)	Aug. (km^2)	Sept. (km^2)	Late Sept. (km^2)	Mean (km^2)	Std. Error (±)
1970								
1973			12,883	12,962	11,829	3,660	10,334	2,239
1974		14,819	11,860	11,698	10,556		12,233	909
1975		13,678	13,385		9,599		12,221	1,315
1976		12,105		11,550	3,380		9,012	2,824
1977		13,245	12,876	11,775	1,891		9,947	2,703
1978		14,250	14,130	12,670	12,000		13,263	553
1979	13,976		11,320		8,704		11,333	1,524
1980		11,330	13,130	12,570	12,520	12,890	12,488	309
1981		15,027	13,750		11,256	5,867	11,475	2,027
1982	11,439	10,974	13,149	11,775	5,538		10,575	1,308
Mean	12,708	13,179	12,943	12,143	8,727	7,472	11,334	
Std Error	1,272	550	292	215	1,206	2,786		505

hypolimnion shows considerable year-to-year variability (Figure 5). No trend is apparent, but the 1975 hypolimnion, with a mean thickness of 7.1 meters, was significantly thicker than all other years.

The year-to-year and seasonal characteristics of the central basin hypolimnion are presented in Tables 7 and 8, respectively, and annual mean trends in hypolimnion thickness, temperature and dissolved oxygen for 1970 to 1982 are given in Table 9. The mean hypolimnion temperature has been relatively consistent over this period, with the exception of 1975 which was significantly colder than other years (Figure 6). The mean dissolved oxygen content (Figure 7) of the hypolimnion does not show a statistically significant trend from 1970 to 1982, but the poorest year, 1973, had a significantly lower content, than the oxygen concentrations measured during the past five years (1978-1982).

In general, the central basin hypolimnion decreases in thickness and area (Figure 8) and in dissolved oxygen (Figure 9) throughout the stratified period, but increases in temperature (Figure 9). The mean monthly trends in these characteristics for 1970 to 1982 are summarized below:

Central Basin Hypolimnion Characteristics

Period (Month)	Thickness (m)	Area (km^2)	Temperature (^oC)	Dissolved Oxygen (mg/l)
May	5.7	12,708	7.7	11.2
June	6.2	13,179	8.6	9.2
July	5.2	12,943	11.1	6.2
August	4.4	12,143	12.2	2.6
September	3.3	8,727	13.1	1.7

Statistical variability and sample sizes for these means are given in Tables 6 and 9.

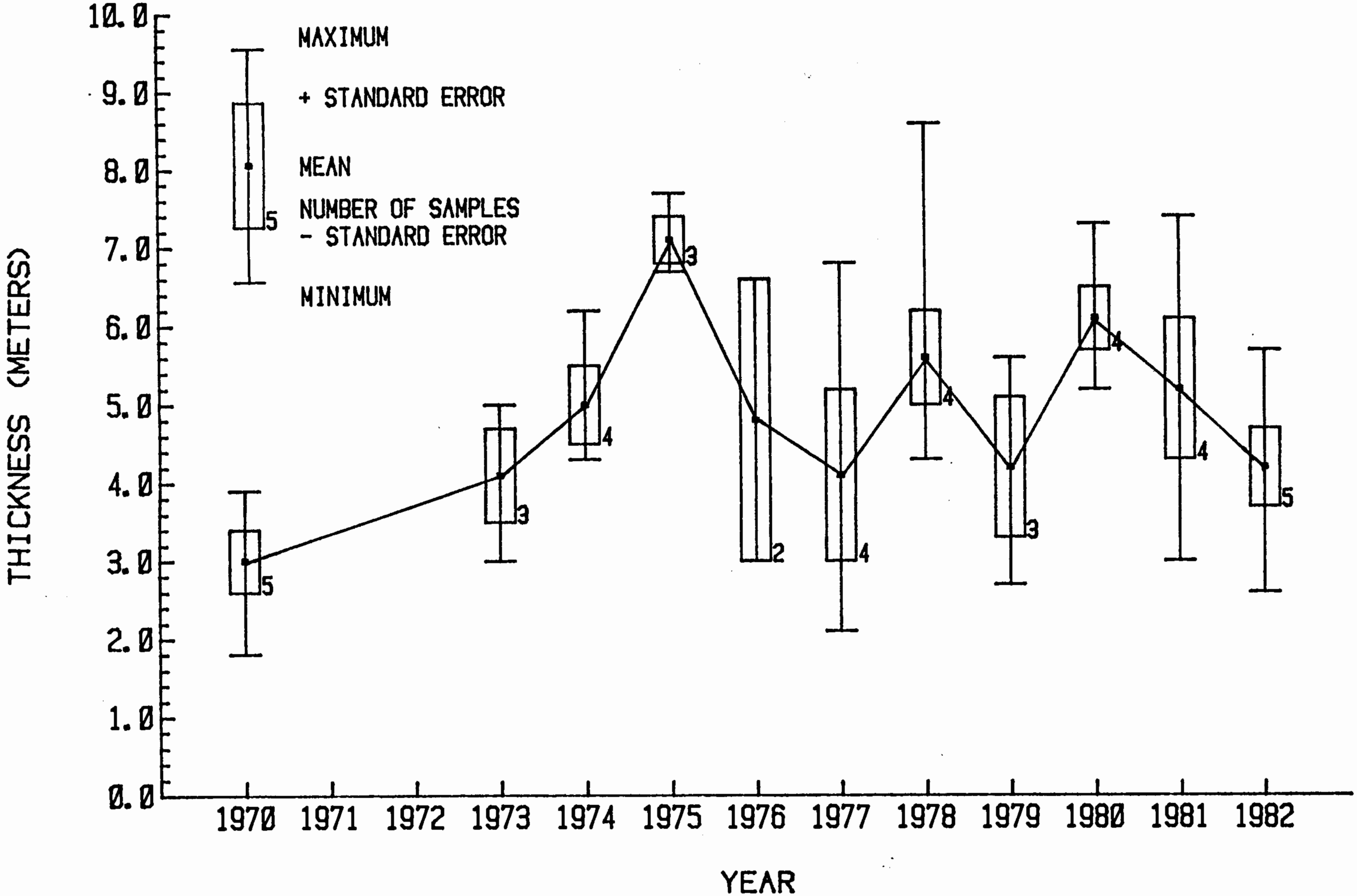


FIGURE 5. LAKE ERIE HYPOLIMNION THICKNESS - CENTRAL BASIN

TABLE 7

LAKE ERIE CENTRAL BASIN HYPOLIMNION THICKNESS, TEMPERATURE AND DISSOLVED OXYGEN

Year	Thickness Min (m)	Thickness Max (m)	Thickness Mean (m)	Thickness Std Error (±)	Temperature Min (^{o}C)	Temperature Max (^{o}C)	Temperature Mean (^{o}C)	Temperature Std Error (±)	Dissolved Oxygen Min (mg/l)	Dissolved Oxygen Max (mg/l)	Dissolved Oxygen Mean (mg/l)	Dissolved Oxygen Std Error (±)	Cruises (N)
1970	1.8	3.9	3.0	0.4	7.5	12.7	10.2	0.9	0.0	9.6	4.3	1.9	5
1973	3.0	5.0	4.1	0.6	10.3	13.8	12.0	1.0	1.1	4.9	2.5	1.2	3
1974	4.3	6.2	5.0	0.5	8.8	13.8	11.5	1.3	0.7	9.9	4.5	2.0	4
1975	6.7	7.7	7.1	0.3	6.5	10.2	8.1	1.1	3.3	10.0	7.0	2.0	3
1976	3.0	6.6	4.8	1.8	9.4	13.7	11.6	2.1	0.7	9.6	5.2	3.7	2
1977	2.1	6.8	4.1	1.1	10.4	11.9	11.1	0.3	0.5	8.3	4.4	2.8	4
1978	4.3	8.6	5.6	0.6	7.0	13.1	11.6	0.9	3.0	12.2	7.8	1.7	4
1979	2.7	5.6	4.2	0.9	9.8	14.0	11.9	2.1	--	--	--	--	2
1980	5.2	7.3	6.1	0.4	6.7	13.1	11.3	1.5	3.0	9.7	6.3	1.5	4
1981	3.0	7.4	5.2	0.9	9.1	14.0	11.5	1.2	2.2	9.4	5.5	1.8	4
1982	2.6	5.7	4.2	0.5	6.4	14.0	10.2	1.3	2.2	11.0	5.9	1.7	5

TABLE 8

LAKE ERIE CENTRAL BASIN HYPOLIMNION CHARACTERISTICS

	1970	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
<u>MAY</u>											
Thick (m)	3.0						8.6	5.6			5.7
DO (mg/l)	9.6						12.2	12.0			11.0
Temp (^{o}C)	7.5						7.0	9.8			6.4
<u>JUNE</u>											
Thick	3.9		6.2	7.7	6.6	6.8	5.6		7.3	7.4	3.9
DO	6.5		9.9	10.0	9.6	8.3	11.0		9.7	9.4	8.3
Temp	8.8		8.8	6.5	9.4	10.4	9.3		6.7	9.1	8.2
<u>JULY</u>											
Thick	3.1	5.0	4.6	6.7		4.6	7.1	4.4	6.2	5.2	4.7
DO	4.0	4.9	5.2	7.8		5.1	7.5	7.2	7.8	7.7	5.2
Temp	10.4	10.3	11.8	7.7		11.0	12.5	14.0	12.7	9.9	10.8
<u>AUGUST</u>											
Thick	2.7	4.4	4.3	6.8	3.0	3.0	5.5		5.8	4.3	4.0
DO	1.2	1.6	2.1	3.3	0.7	2.1	5.4		4.5	2.2	2.7
Temp	11.6	11.9	13.5	10.2	13.7	11.9	11.5		13.1	12.8	11.4

TABLE 8 (CONTINUED)

	1970	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
SEPTEMBER											
Thick	1.8	3.0	4.6			2.1	4.3	2.7	5.2	3.0	2.6
DO	0.0	1.1	0.7			0.5	3.0		3.0	2.7	2.2
Temp	12.7	13.8	13.8			11.2	13.1		12.5	14.0	14.0
NET OXYGEN DEMAND											
Volume rate: (mg/l)	0.11	0.12	0.13	0.10	0.13	0.13	0.09	0.09	0.11	0.09	0.11
Area rate: (g/m^2)	0.38	0.53	0.60	0.67	0.75	0.58	0.51	0.41	0.63	0.47	0.47

TABLE 9

ANNUAL MEAN TRENDS IN LAKE ERIE CENTRAL BASIN HYPOLIMNION CHARACTERISTICS (1970-1982)

Month	Thickness				Temperature				Dissolved Oxygen				
	Min (m)	Max (m)	Mean (m)	Std Error (±)	Min (^oC)	Max (^oC)	Mean (^oC)	Std Error (±)	Min (mg/l)	Max (mg/l)	Mean (mg/l)	Std Error (±)	Cruises (N)
MAY	3.0	8.6	5.7	1.1	6.4	9.8	7.7	0.7	9.6	12.2	11.2	0.6	4
JUNE	3.9	7.7	6.2	0.5	6.5	10.4	8.6	0.4	6.5	11.0	9.2	0.4	9
JULY	3.1	7.1	5.2	0.4	7.7	14.0	11.1	0.6	4.0	7.8	6.2	0.5	10
AUGUST	3.0	5.8	4.4	0.4	10.2	13.7	12.2	0.3	0.7	5.4	2.6	0.5	10
SEPTEMBER	1.8	5.2	3.3	0.4	11.2	14.0	13.1	0.3	0.0	3.0	1.7	0.4	9

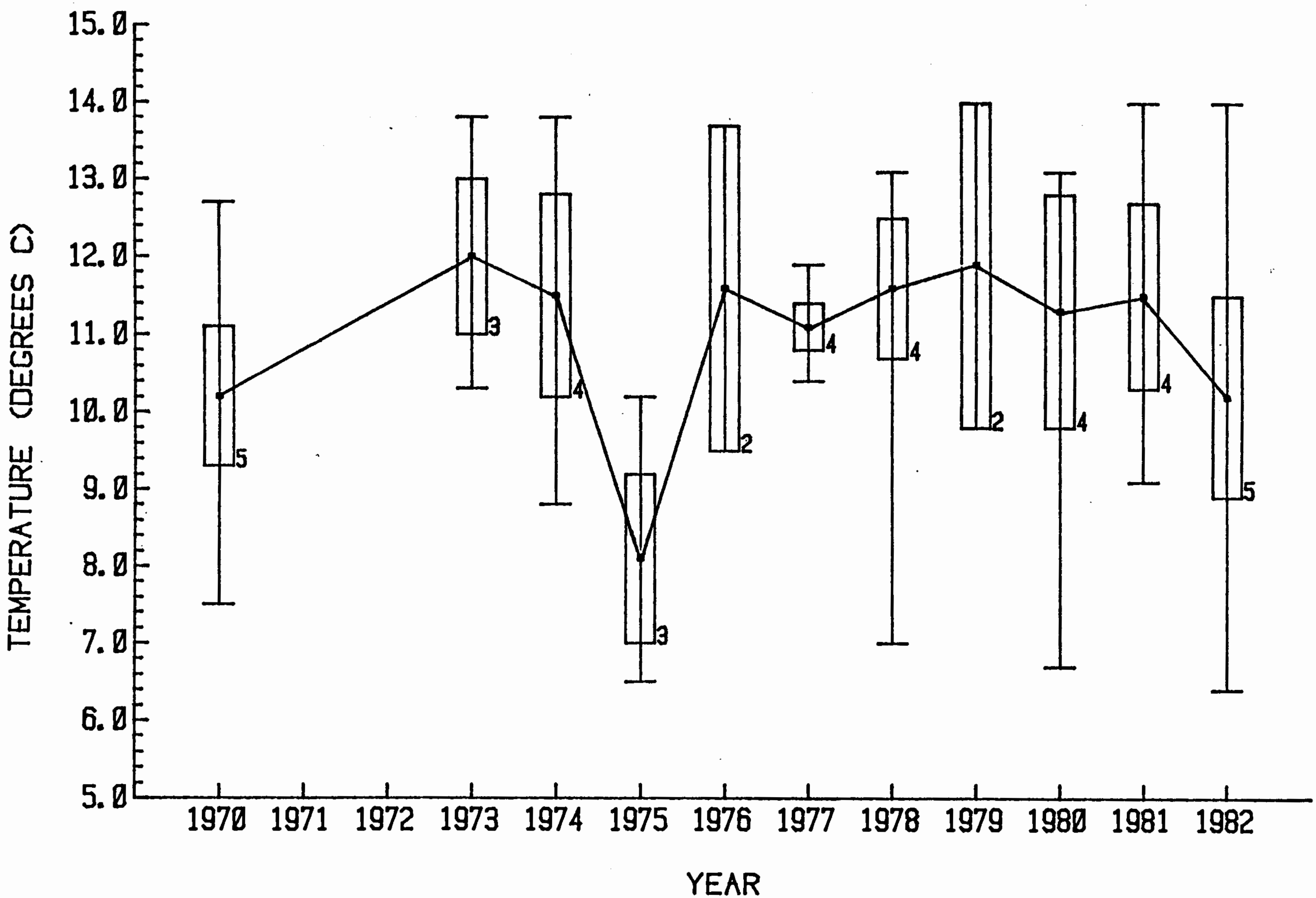


FIGURE 6. LAKE ERIE HYPOLIMNION TEMPERATURE - CENTRAL BASIN

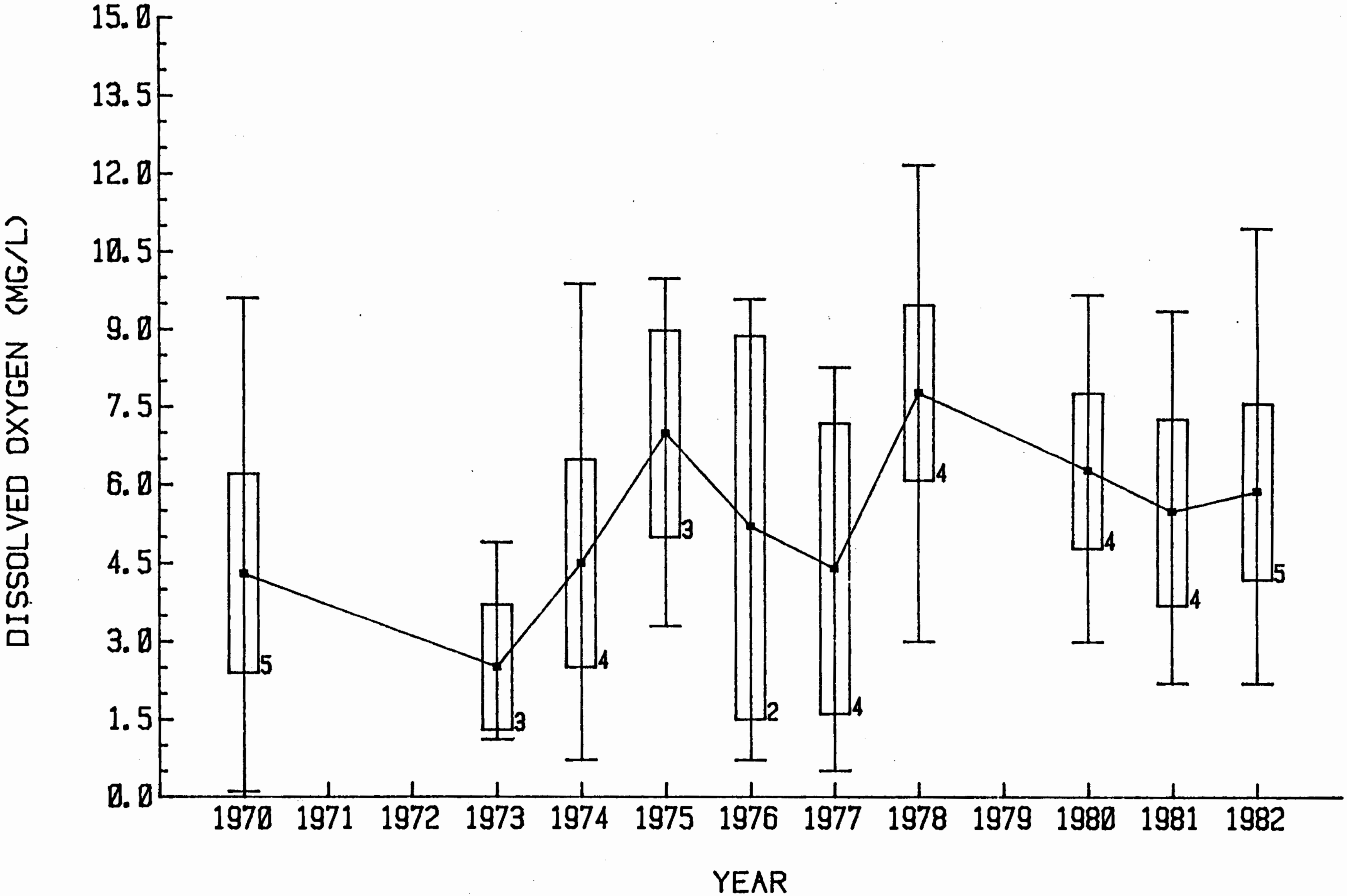


FIGURE 7. LAKE ERIE HYPOLIMNION DISSOLVED OXYGEN - CENTRAL BASIN

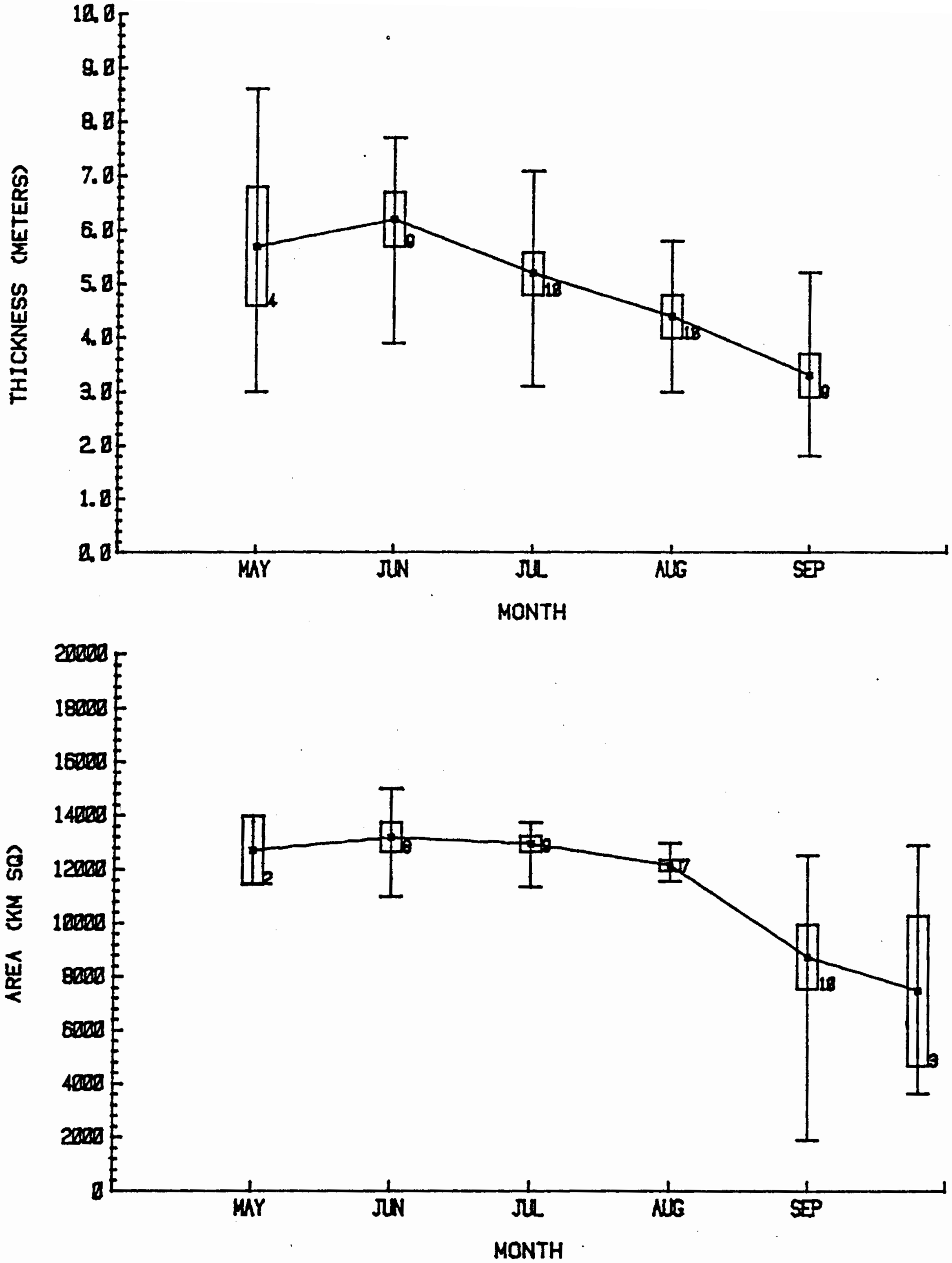


FIGURE 8. LAKE ERIE HYPOLIMNION - MEAN ANNUAL TRENDS IN THICKNESS AND AREA FOR CENTRAL BASIN (1970 - 1982)

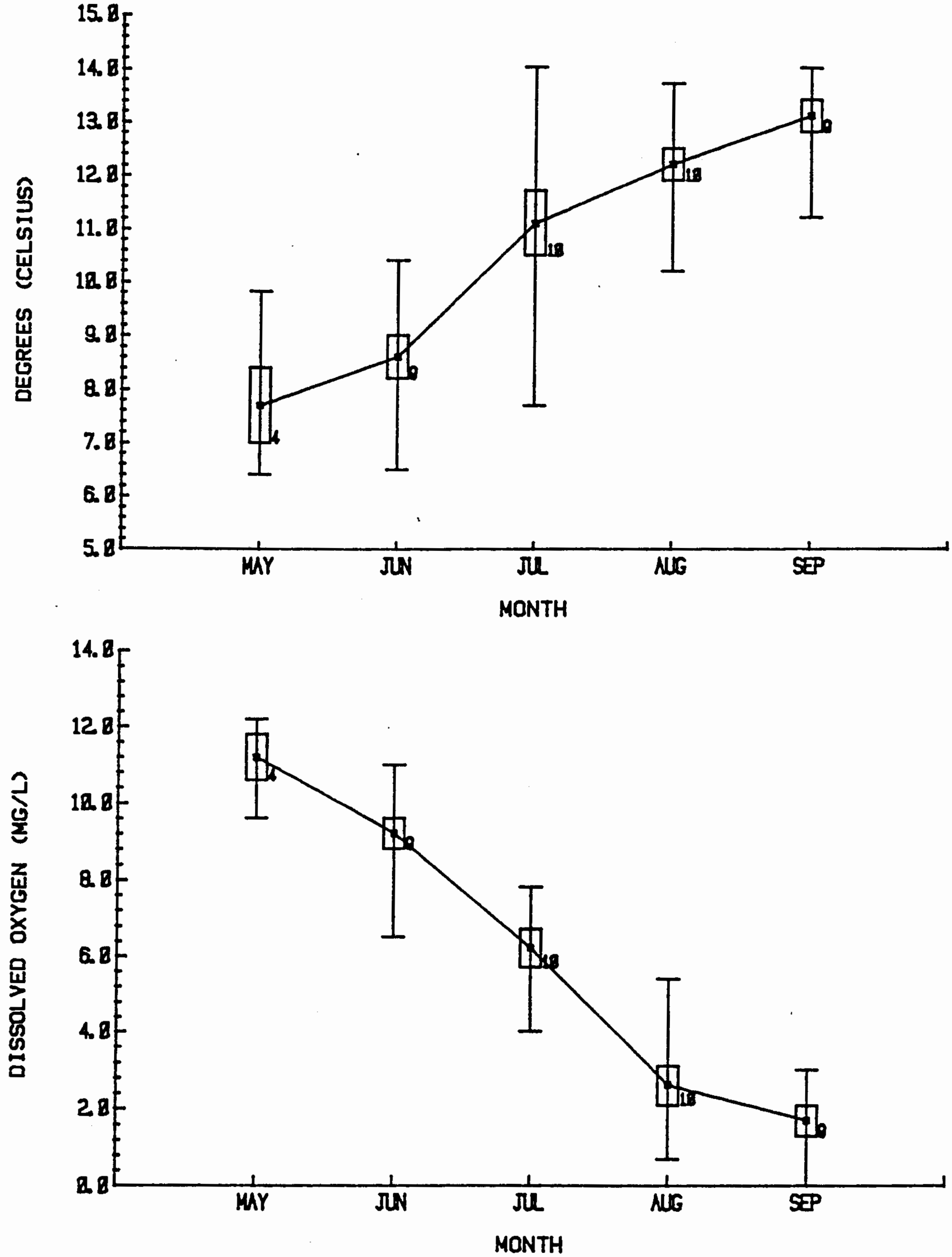


FIGURE 9. LAKE ERIE HYPOLIMNION - MEAN ANNUAL TRENDS IN TEMPERATURES AND DISSOLVED OXYGEN FOR CENTRAL BASIN (1970 - 1982)

The seasonal pattern for the thermal structure of central Lake Erie is shown in Figure 10. Once the thermocline is well established, generally in late June, the mesolimnion remains relatively uniform in thickness as the epilimnion thickens at the expense of the hypolimnion. Eventually, the cooling of the surface water forces the epilimnion to the bottom of the lake, eliminating the other limnions at "turnover." This thinning of the hypolimnion increases the bottom surface area to water volume ratio in the hypolimnion, which tends to increase the effect of sediment oxygen demand (SOD) on the remaining hypolimnetic water.

The eastern basin of Lake Erie is normally stratified from June through October or early November. The mean thicknesses of the epilimnion, mesolimnion and hypolimnion during 1978 are presented below:

Eastern Lake Erie Thermal Strata

Limnion	Thickness (m) (+ std error)	Cruises (N)
Epilimnion	13.1 + 2.7	5
Mesolimnion	8.5 + 1.8	5
Hypolimnion	12.5 + 0.5	5

Generally the hypolimnion in the eastern basin is of sufficient thickness that severe oxygen depletion problems do not develop.

The thermal structure of Lake Erie is highly dependent on wind and other meteorological conditions. Calm weather in the western basin can be effective in forming transitory stratification during the summer months. In the central and eastern basins, calm weather during the late spring can result in a shallow thermocline and a correspondingly thick hypolimnion. This situation occurred in 1975 with a dramatic impact on dissolved oxygen concentrations in the central basin hypolimnion. Herdendorf (1980) documented that in 1975 the thickness of the hypolimnion was considerably thicker than earlier years of the decade and that the oxygen depletion rate was lower and the areal extent of anoxia was greatly reduced (see Figures 12 and 15 for comparison with other years).

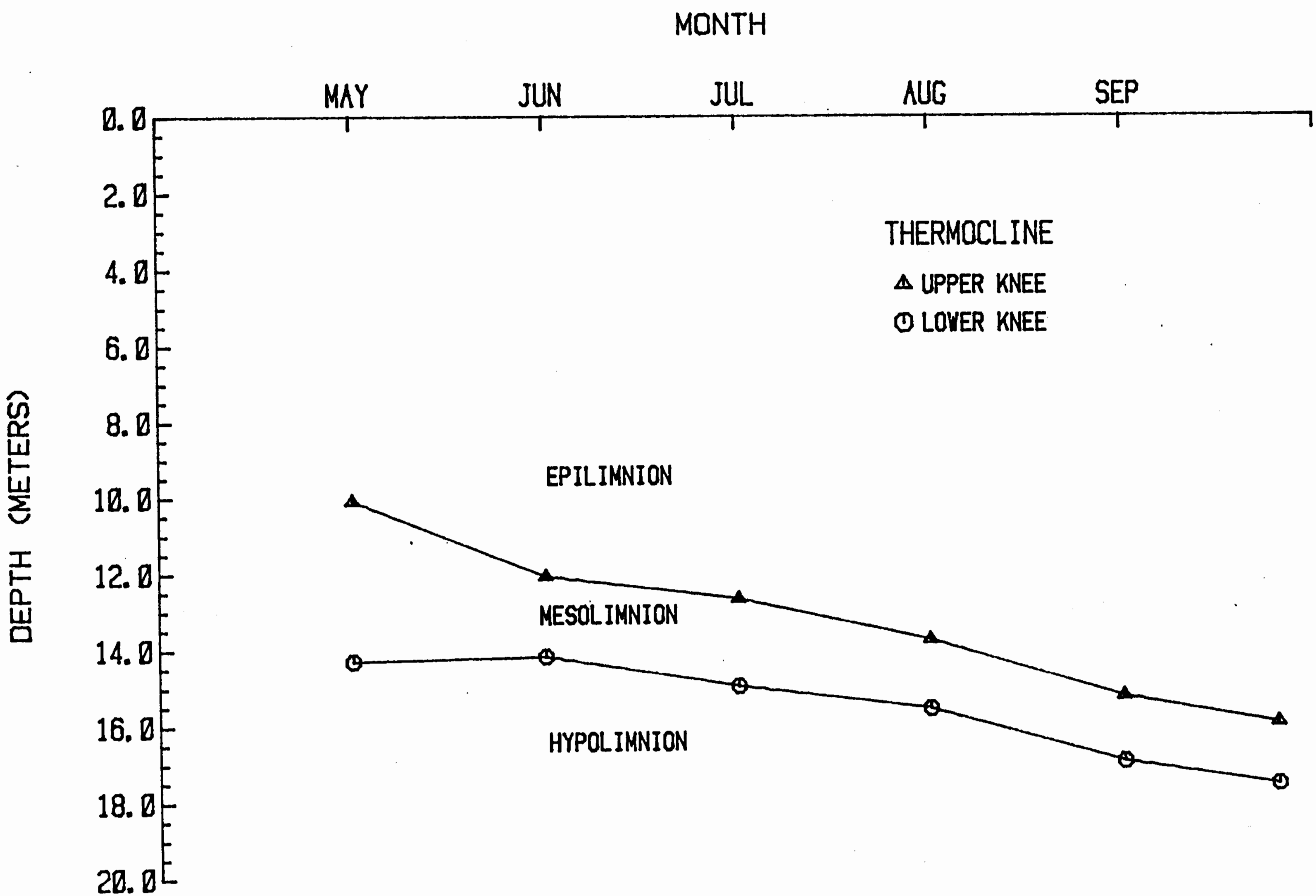


FIGURE 10. LAKE ERIE THERMAL STRUCTURE - MEAN ANNUAL TREND IN LIMNION THICKNESSES FOR CENTRAL BASIN (1970 - 1982)

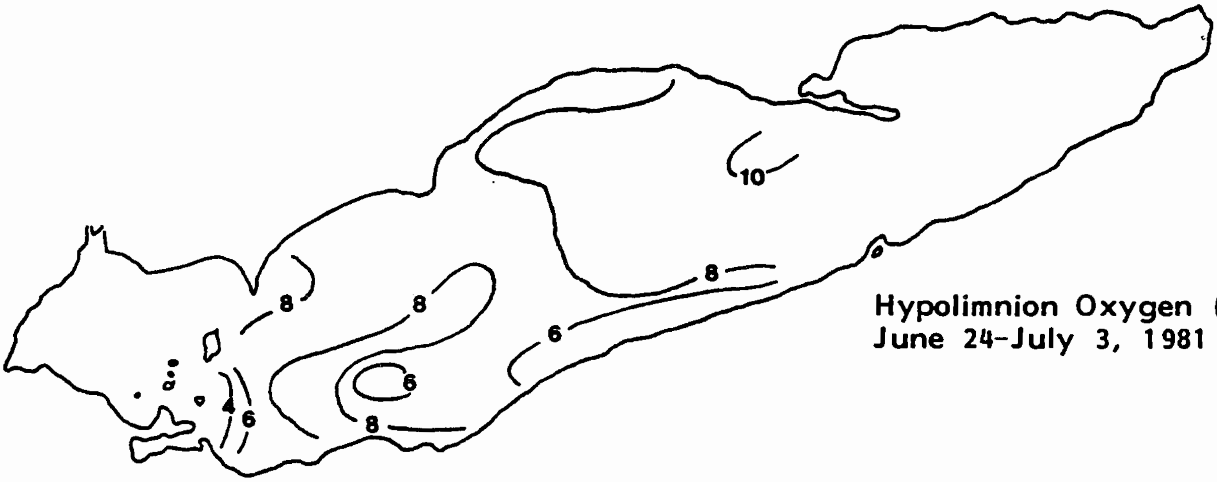
Dissolved oxygen. Low concentrations of dissolved oxygen, particularly in the central basin hypolimnion, is one of the most important environmental problems plaguing Lake Erie. Small areas of anoxic water in the central basin were observed as early as 1930 (Fish 1960). The size of the late summer anoxic portion of the lake continued to grow for the next several decades until 1973, when approximately 94% of the hypolimnion had oxygen concentrations below 0.5 mg/l (Herdendorf 1980). More recent surveys have shown wide fluctuations in the size of the anoxic area in the central basin, primarily due to the meteorological conditions discussed earlier for 1975; however, the area and the percentage of the hypolimnion experiencing anoxia have declined markedly in the period 1977 to 1982, as seen below:

Central Lake Erie Anoxic Area Trends

Period	Anoxic Area (km^2) (± std error)	Percent Hypolimnion	Percent Total Basin	Years (N)
1970-1976*	8,678 ± 890	75.2 ± 6.0	55.2 ± 5.2	5
1977-1982	4,294 ± 434	35.2 ±3.6	27.0 ± 2.2	5

*1975 excluded

Typically, the central basin hypolimnion contains about 8 mg/l of dissolved oxygen in late June, but by early September this has been reduced to less than 1 mg/l over much of the basin. Figure 11 depicts the distribution of hypolimnetic oxygen in 1981 and illustrates the loss of oxygen during the stratified period. This pattern is typical of the depletion process which has occurred during the past five years.



Hypolimnion Oxygen (mg/1)
June 24-July 3, 1981

Hypolimnion Oxygen (mg/1)
September 1-11, 1981

FIGURE 11. DISTRIBUTION OF DISSOLVED OXYGEN IN LAKE ERIE CENTRAL BASIN HYPOLIMNION (1981)

One method of determining trends in oxygen concentrations involves measuring the rate of loss in oxygen in the interval between two cruises. Table 10 provides a list of the calculated central basin oxygen demand for the period 1970 to 1982, expressed as both oxygen loss per unit volume of water (mg/l) and loss per unit area (g/m^2) per day between two cruises. Table 11 shows estimates of oxygen demand for both the central and eastern basin by various investigators for the period 1930 to 1982. The general inference that can be drawn from the rate measurement data is that the hypolimnetic oxygen demand in the central basin increased during the period 1930 to 1970, remained relatively stable during the mid-1970s (with the exception of 1975 which has been discussed earlier), and declined slightly during the last five years (Figure 12). The daily losses per unit volume and unit area (with standard error estimate) for these three blocks of years are summarized below:

Central Basin Hypolimnetic Oxygen Demand

Period	Volumetric Loss Rate (mg/l/day)	Areal Loss Rate ($g/m^2/day$)
1930-1970	0.079 ± 0.010	0.25 ± 0.06
1970-1976*	0.123 ± 0.010	0.57 ± 0.08
1977-1982	0.107 ± 0.006	0.52 ± 0.03

*1975 excluded

From these data the significant increase in the rate of oxygen loss from 1930 to 1970 is obvious, but the recent decline may not be significant but merely a slight downward trend in the relative stable period that has persisted since 1970. This stability in central basin hypolimnetic oxygen demand from 1970 to 1982, particularly during the

TABLE 10

LAKE ERIE CENTRAL BASIN HYPOLIMNETIC OXYGEN DEMAND

Year	Volumetric Loss Rate Min (mg/l/day)	Volumetric Loss Rate Max (mg/l/day)	Volumetric Loss Rate Mean (mg/l/day)	Volumetric Loss Rate Std Error (+)	Area Loss Rate Min (g/m^2/day)	Area Loss Rate Max (g/m^2/day)	Area Loss Rate Mean (g/m^2/day)	Area Loss Rate Std Error (+)	Cruise Intervals (N)
1970	0.110	0.120	0.113	0.003	0.36	0.39	0.38	0.01	3
1973	0.100	0.130	0.120	0.014	0.46	0.60	0.53	0.07	2
1974	0.100	0.190	0.130	0.025	0.42	0.85	0.60	0.10	4
1975	0.070	0.120	0.100	0.028	0.53	0.80	0.67	0.13	2
1976	0.130	0.130	0.130	0.000	0.75	0.75	0.75	0.00	1
1977	0.086	0.149	0.120	0.011	0.35	0.63	0.48	0.05	5
1978	0.073	0.149	0.111	0.015	0.34	0.93	0.54	0.11	5
1980	0.101	0.116	0.109	0.008	0.61	0.64	0.63	0.01	2
1981	0.073	0.097	0.085	0.014	0.46	0.47	0.47	0.00	2
1982	0.102	0.121	0.111	0.009	0.44	0.51	0.47	0.02	4

TABLE 11

TRENDS IN NET OXYGEN DEMAND OF THE CENTRAL AND EASTERN BASINS HYPOLIMNIONS OF LAKE ERIE (1930-1982)

DATA SOURCE	YEAR	NET OXYGEN DEMAND PER DAY			
		Rate Per Unit Area (g/m^2)		Rate Per Unit Volume (mg/1)	
		Central Basin	Eastern Basin	Central Basin	Eastern Basin
1	1930	0.08	--	0.054	0.023
1	1940	0.15	--	0.067	0.027
1	1950	0.25	--	0.070	0.032
1	1960	0.37	--	0.093	0.036
2	1970	0.38	0.70	0.110	0.055
3,4	1973	0.53	0.23	0.120	0.016
3,4	1974	0.60	0.57	0.130	0.026
3,4	1975	0.67	0.76	0.100	0.040
3,4	1976	0.75	--	0.130	0.032
3	1977	0.58	0.68	0.130	0.060
2	1977	0.48	0.51	0.120	0.065
5	1978	0.51	0.58	0.092	0.048
2	1978	0.54	0.61	0.111	0.047
5	1979	0.41	0.58	0.090	0.049
3	1980	0.63	--	0.109	--
3	1981	0.47	--	0.085	--
3	1982	0.47	--	0.111	--

Data sources: (1) Dobson and Gilbertson (1971); (2) CCIW--Noel Burns, personal communication; (3) OSU/CLEAR--Central Basin, 1973-1977, 1980-1982; Eastern Basin, 1977; (4) SUNY/GLL--Eastern Basin, 1973-1976; (5) USEPA/GLNPO--rate calculation, OSU/CLEAR.

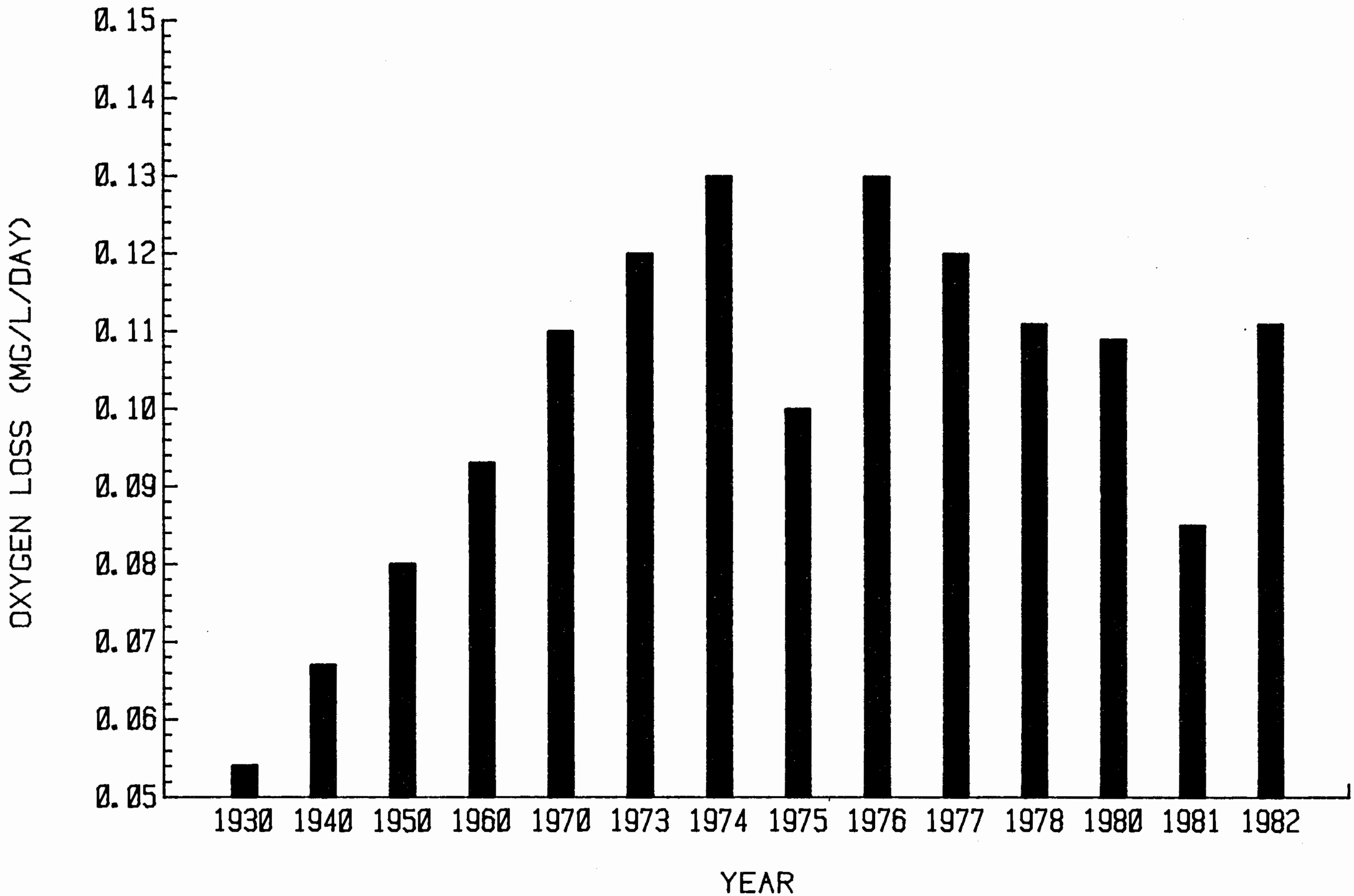


FIGURE 12. LAKE ERIE HYPOLIMNION OXYGEN DEMAND - CENTRAL BASIN

month of August, is illustrated in Figure 13. This tight cluster of data points suggest that August is the more opportune month to obtain oxygen depletion measurements for rate comparisons.

Early oxygen depletion data is not available for the eastern basin. A slight increase may be indicated from the first half to the second half of the past decade; however, the data in Table 11 shows an erratic pattern in the early 1970s, which may be the result of diverse analytical techniques.

Another method of assessing the oxygen status of the central basin hypolimnion is comparing the relative sizes of anoxic areas from year to year. Anoxia is here defined as dissolved oxygen concentrations of less than 0.5 mg/l as measured 1.0 meters above the sediment-water interface. Figure 14 is a mosaic of Lake Erie maps from 1930 to 1982 showing the 15 years where reasonably good data exists for the areal extent of anoxia. The estimated areas of the anoxic hypolimnion are presented in Table 12 and shown graphically in Figure 15. The obvious conclusion is that the area of the central basin experiencing anoxia increased dramatically from 1930 to the mid-1970s and since that time has declined to approximately half of the maximum area.

Clarity. Water clarity is an indicator of both phytoplankton biomass and inorganic particulate matter suspended in the water column. Turbidity patterns mirror those that will be presented for total phosphorus. Central and eastern basin turbidity is primarily the result of the organic component, whereas in the western basin spring meltwaters carry a large component of inorganic solids to the lake.

An analysis of Lake Erie transparency was performed for the period 1973-1982 by area-weighting secchi disk results from 33 cruises in the western basin, 37 in the central basin and 10 in the eastern basin (Table 13). No significant trends or improvements are demonstrated by the data. The mean summer values for 4-year periods are summarized below:

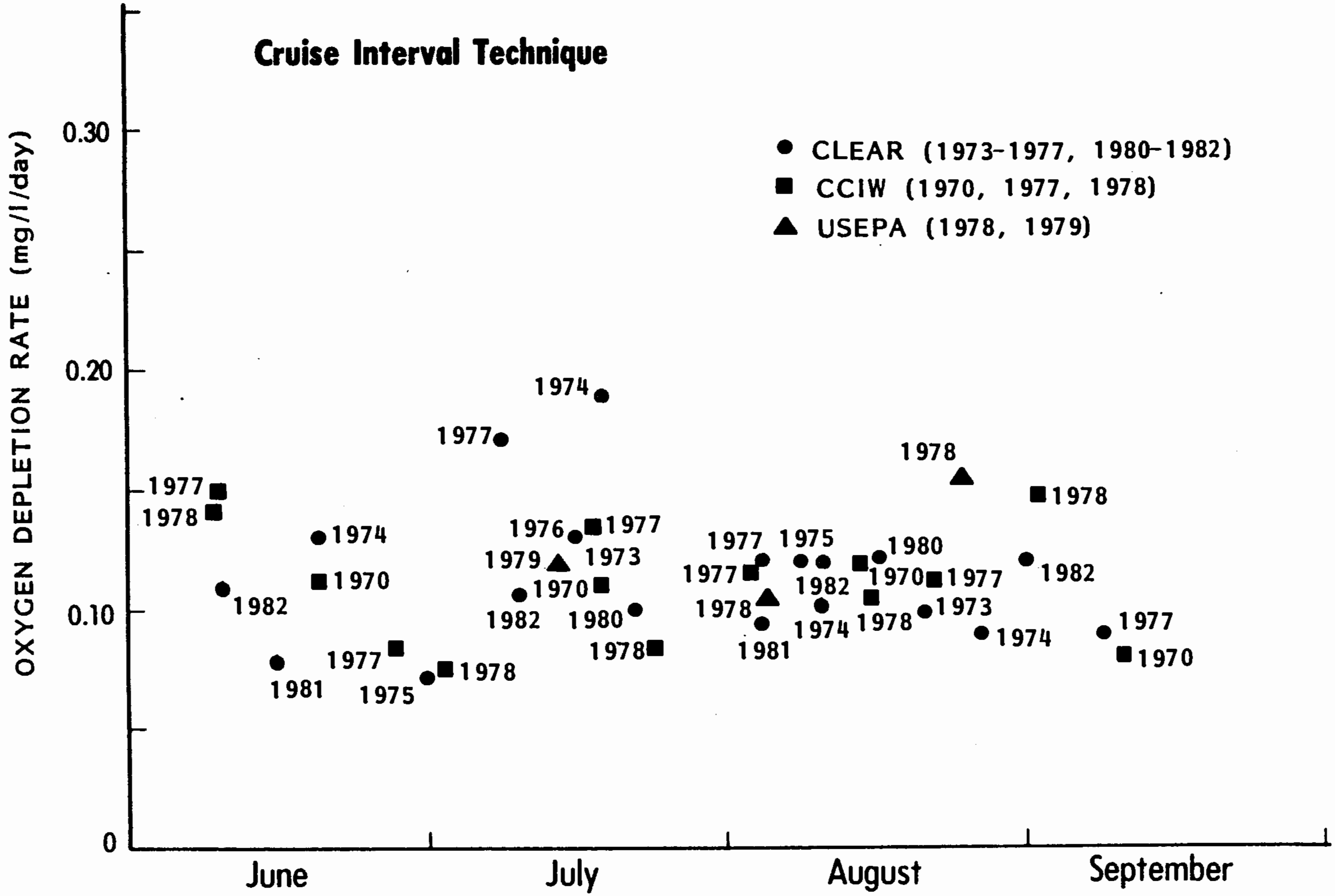


FIGURE 13. LAKE ERIE HYPOLIMNION OXYGEN DEMAND-SEASONAL DEPLETION RATES FOR CENTRAL BASIN (1970-1982)

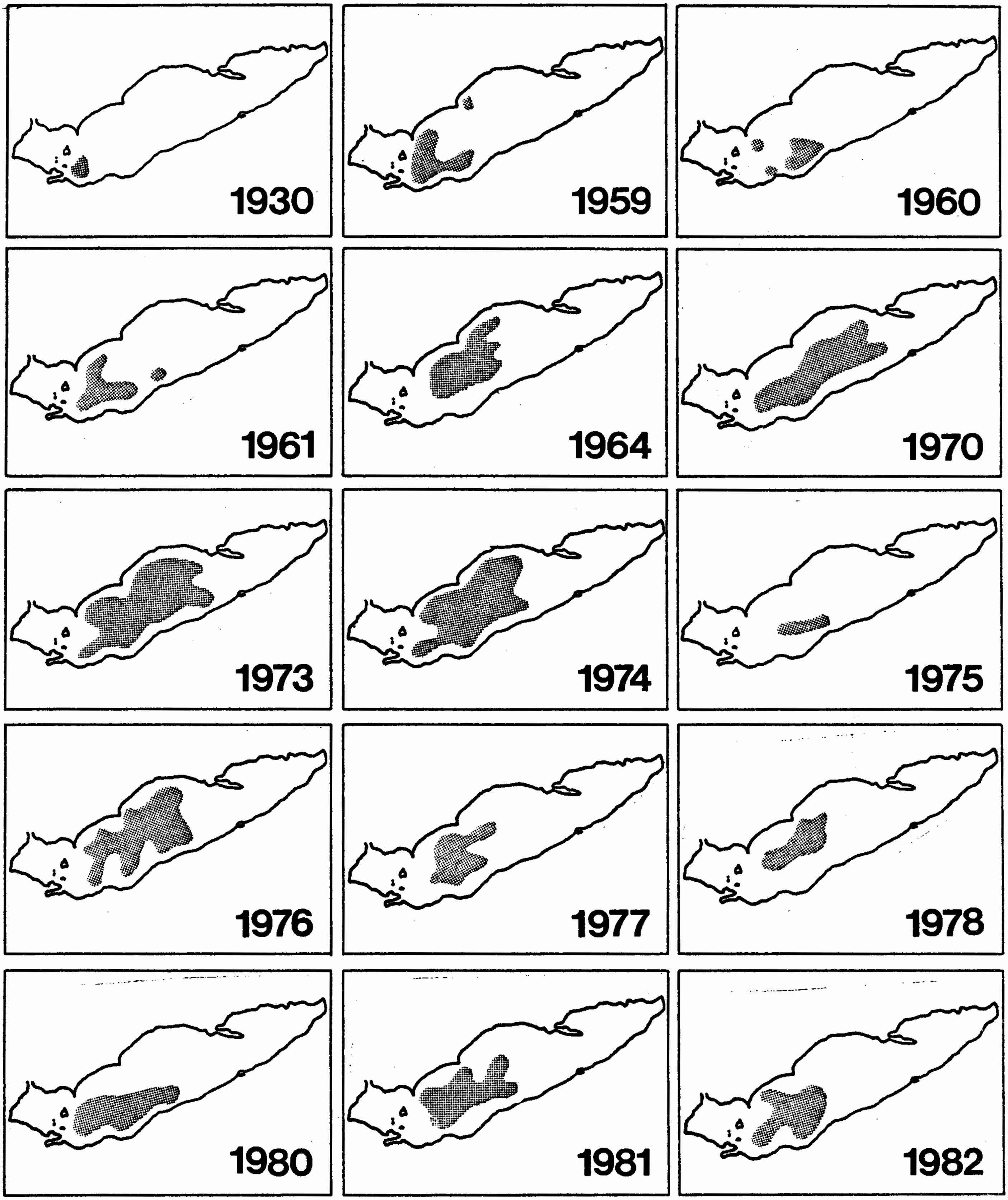


FIGURE 14. DISTRIBUTION OF ANOXIA IN LAKE ERIE (1930 - 1982).

TABLE 12

ESTIMATED AREA OF THE ANOXIC HYPOLIMNION OF THE CENTRAL BASIN OF LAKE ERIE (1930-1982)

Year	Anoxic Area (km^2)	Percent of Central Basin: Hypolimnion (%)	Percent of Central Basin: Total Basin (%)
1930	300	3.0	1.9
1959	3,600	33.0	22.3
1960	1,660	15.0	10.3
1961	3,640	33.0	22.5
1964	5,870	53.0	36.3
1970	6,600	60.0	40.4
1972	7,970	72.5	49.3
1973	11,270	93.7	69.8
1974	10,250	87.0	63.4
1975	400	4.1	2.5
1976	7,300	63.0	53.0
1977	2,870	24.8	20.8
1978	3,980	31.4	24.6
1980	4,330	35.9	26.8
1981	4,820	37.4	29.0
1982	5,470	46.5	33.9

Data Sources:
- 1930--Fish (1960)
- 1959-1961--Thomas (1963)
- 1964--FWPCA (1968a)
- 1970--CCIW (Burns and Ross 1972)
- 1972-1977, 1980-1982--OSU/CLEAR
- 1978--ANL (Zapotosky and White 1980)

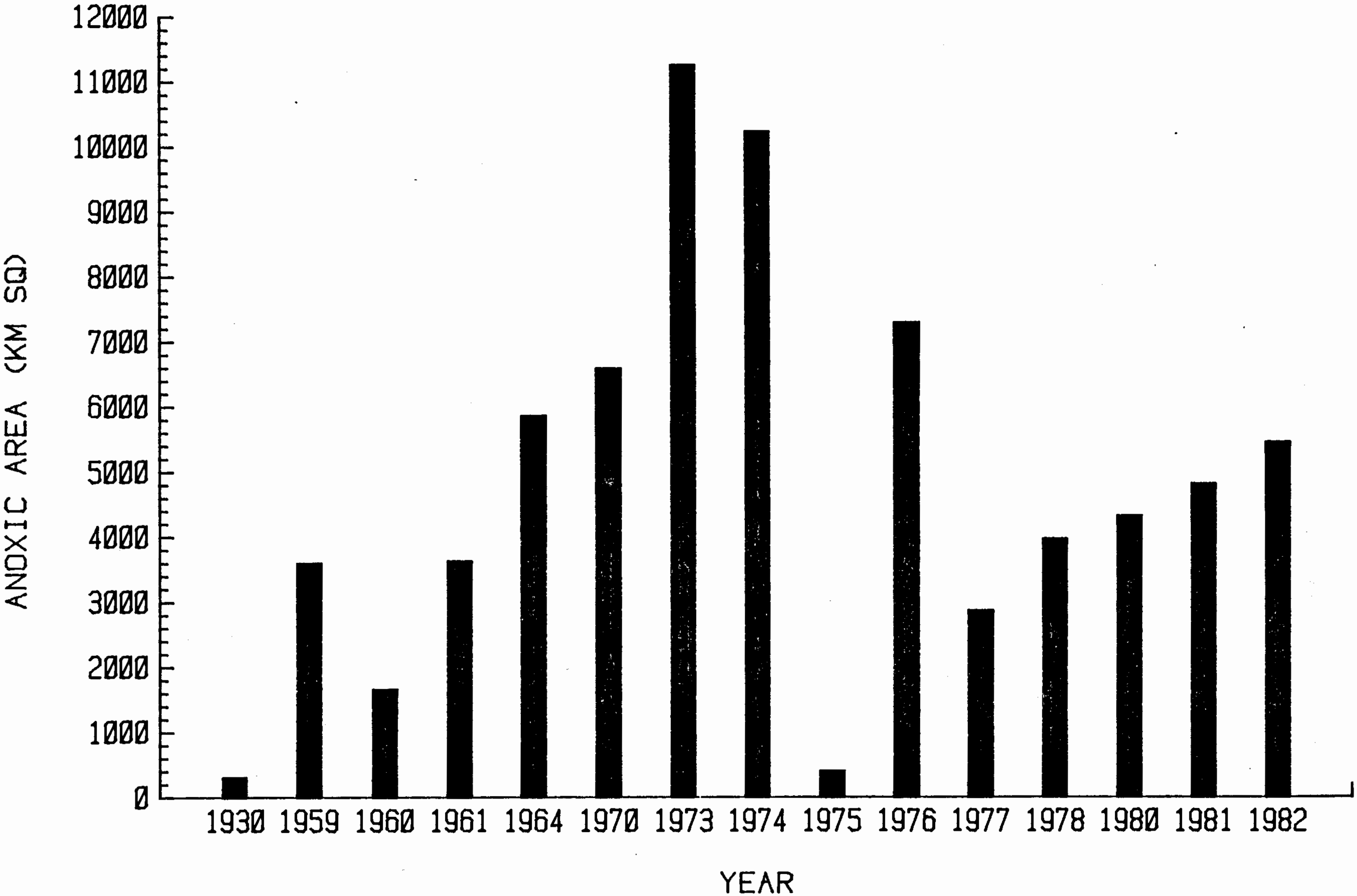


FIGURE 15. LAKE ERIE HYPOLIMNION - AREA OF ANOXIA FOR CENTRAL BASIN

TABLE 13

LAKE ERIE SUMMER SECCHI DISK TRANSPARENCY

Year	Western Basin				Central Basin				Eastern Basin				Cruises (N)		
	Min (m)	Max (m)	Mean (m)	Std Error (±)	Min (m)	Max (m)	Mean (m)	Std Error (±)	Min (m)	Max (m)	Mean (m)	Std Error (±)	W	C	E
1973	1.78	2.12	1.94	0.10	4.31	6.72	5.45	0.45	--	--	--	--	3	5	--
1974	1.25	2.35	1.72	0.22	4.38	6.36	5.69	0.36	--	--	--	--	5	5	--
1975	0.79	1.56	1.21	0.23	3.63	7.99	5.51	1.29	--	--	--	--	3	3	--
1976	0.85	2.78	1.82	0.96	4.39	4.42	4.41	0.01	--	--	--	--	2	2	--
1977	1.09	1.09	1.09	0.00	4.69	6.55	5.55	0.54	3.69	7.21	5.60	1.03	1	3	3
1978	1.94	2.68	2.14	0.13	4.22	6.93	5.52	0.65	4.22	7.03	5.74	0.57	5	5	5
1979	1.44	3.03	2.19	0.34	3.49	5.80	5.02	0.77	3.07	6.91	4.99	1.40	4	3	2
1980	1.50	1.73	1.58	0.08	4.66	7.02	5.88	0.68	--	--	--	--	3	3	--
1981	0.59	1.19	0.87	0.17	2.77	6.08	4.02	1.04	--	--	--	--	3	3	--
1982	0.95	2.24	1.62	0.27	3.21	6.66	4.93	0.73	--	--	--	--	5	5	--

Secchi Disk Transparency for Lake Erie

Period	Western Basin (m ± std error)	Central Basin (m ± std error)	Eastern Basin (m ± std error)
1973-1976	1.67 ± 0.16	5.27 ± 0.29	
1976-1979	1.81 ± 0.25	5.13 ± 0.27	5.54 ± 0.17
1979-1982	1.57 ± 0.27	4.96 ± 0.38	

The year with the poorest water clarity for the western basin (Figure 16) and the central basin (Figure 17) was recorded in 1981 which coincides with a year that experienced severe late spring storms and associated resuspension of bottom sediments. Even with these low values, the transparency in the western and central basins was relatively constant throughout the 10-year period. From the limited data for the eastern basin, it appears that mean transparencies in the eastern and central basins are very similar. In general, the central basin transparency exceeds that of the western basin by a factor of three.

Dissolved Substances. Trends in dissolved substances in Lake Erie water can be inferred from long-term records of Lake Erie conductivity measurements and determination of major conservative ions, such as sulfate and chloride. Central basin cruise data for 1970 to 1982 (Figure 18) indicates a significant decline in specific conductance. The typical distributions of the major dissolved ions in Lake Erie (alkalinity, conductivity, calcium, sulfate, chloride, sodium, magnesium, and potassium) are illustrated in Figure 19. The tendency is for most substances to increase from west to east as water flows through the basins. USEPA/GLNPO, using STORET data files for the period 1966 to 1980, performed a trend analysis for conductivity, chloride and sulfate based on central basin cruise data supplied by CCIW, OME, GLNPO and CLEAR. OME data was obtained from stations 1-7 km offshore,

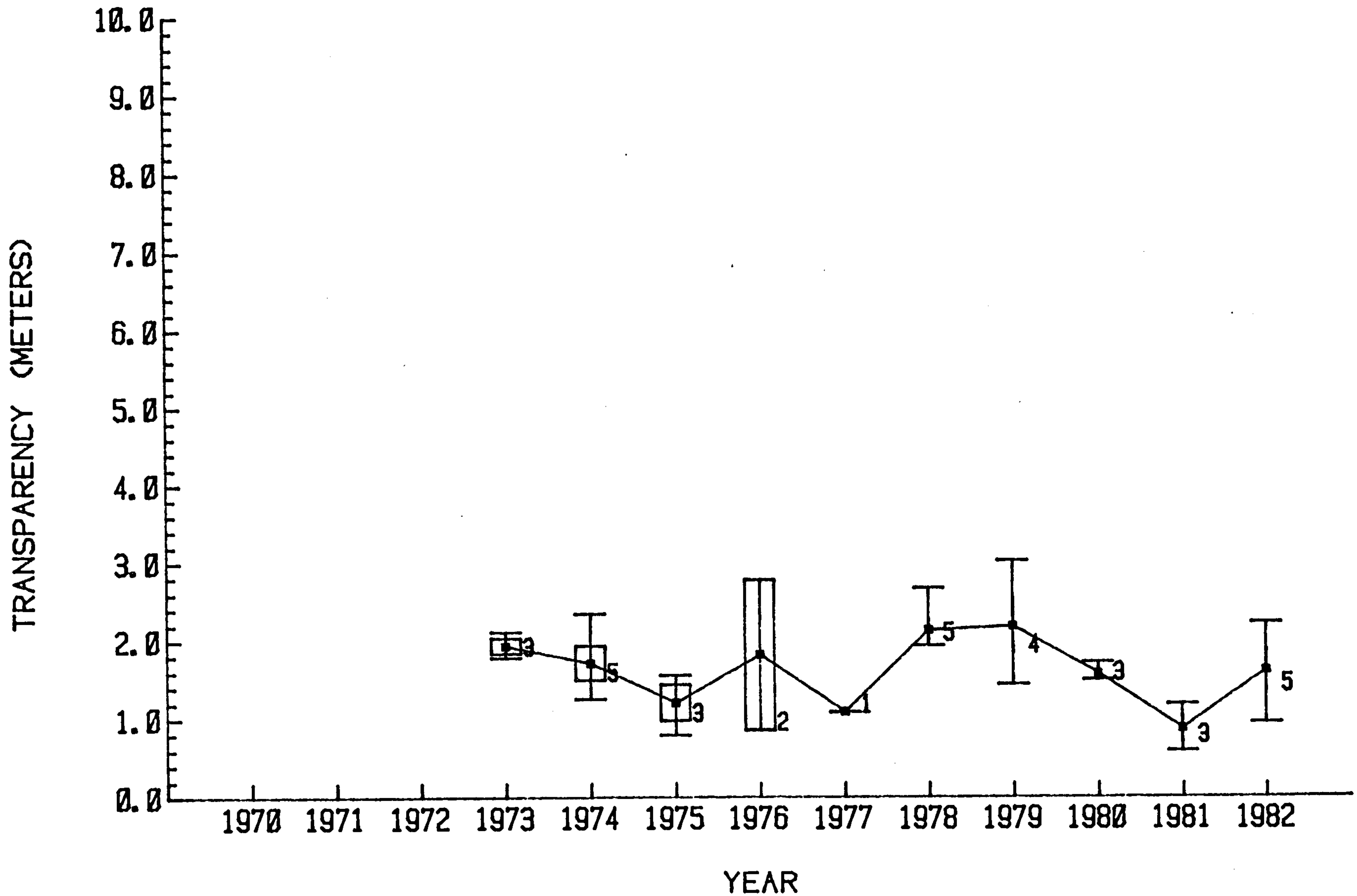


FIGURE 16. LAKE ERIE SUMMER SECCHI DISK TRANSPARENCY - WESTERN BASIN

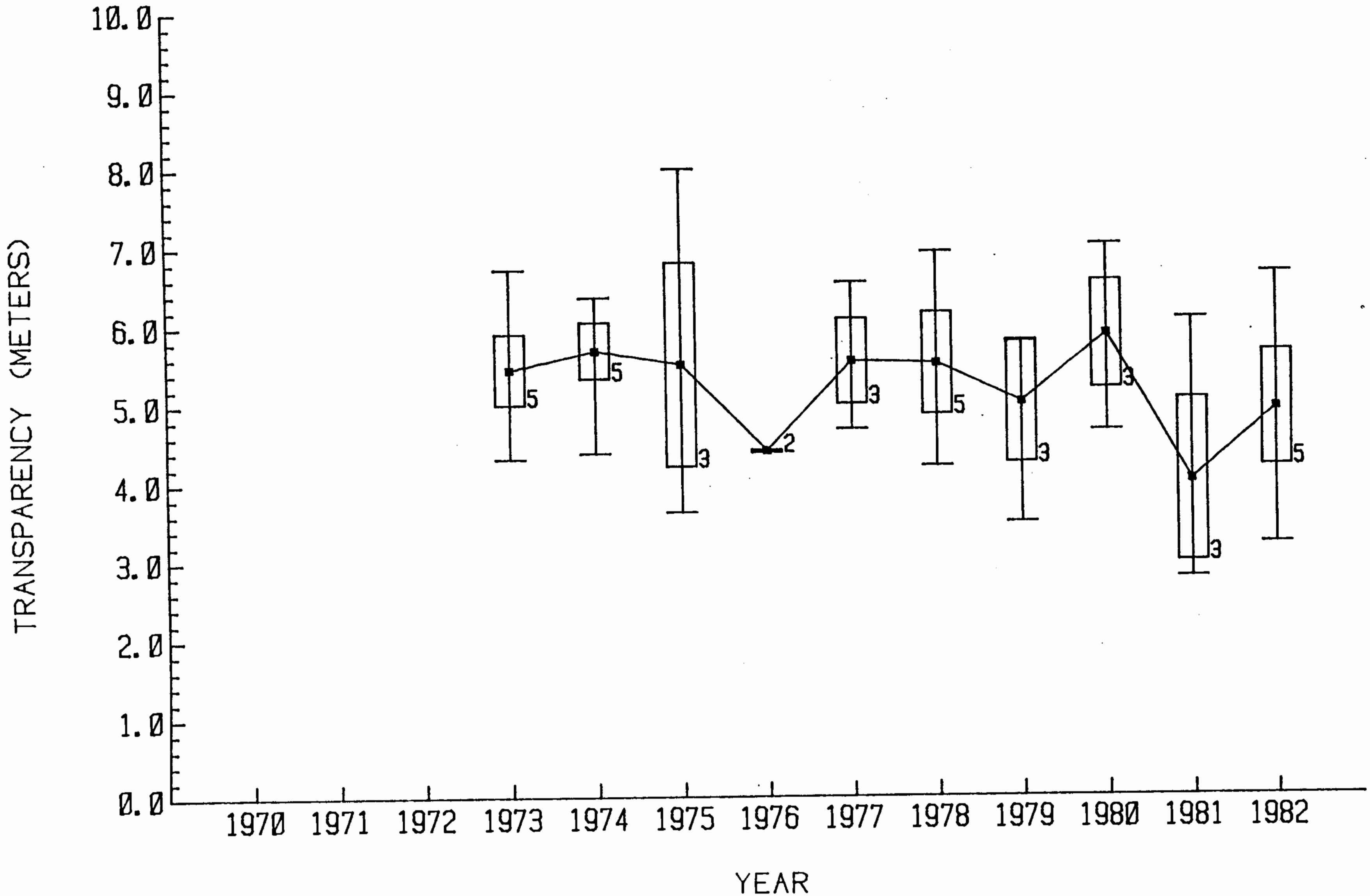


FIGURE 17. LAKE ERIE SUMMER SECCHI DISK TRANSPARENCY –
CENTRAL BASIN

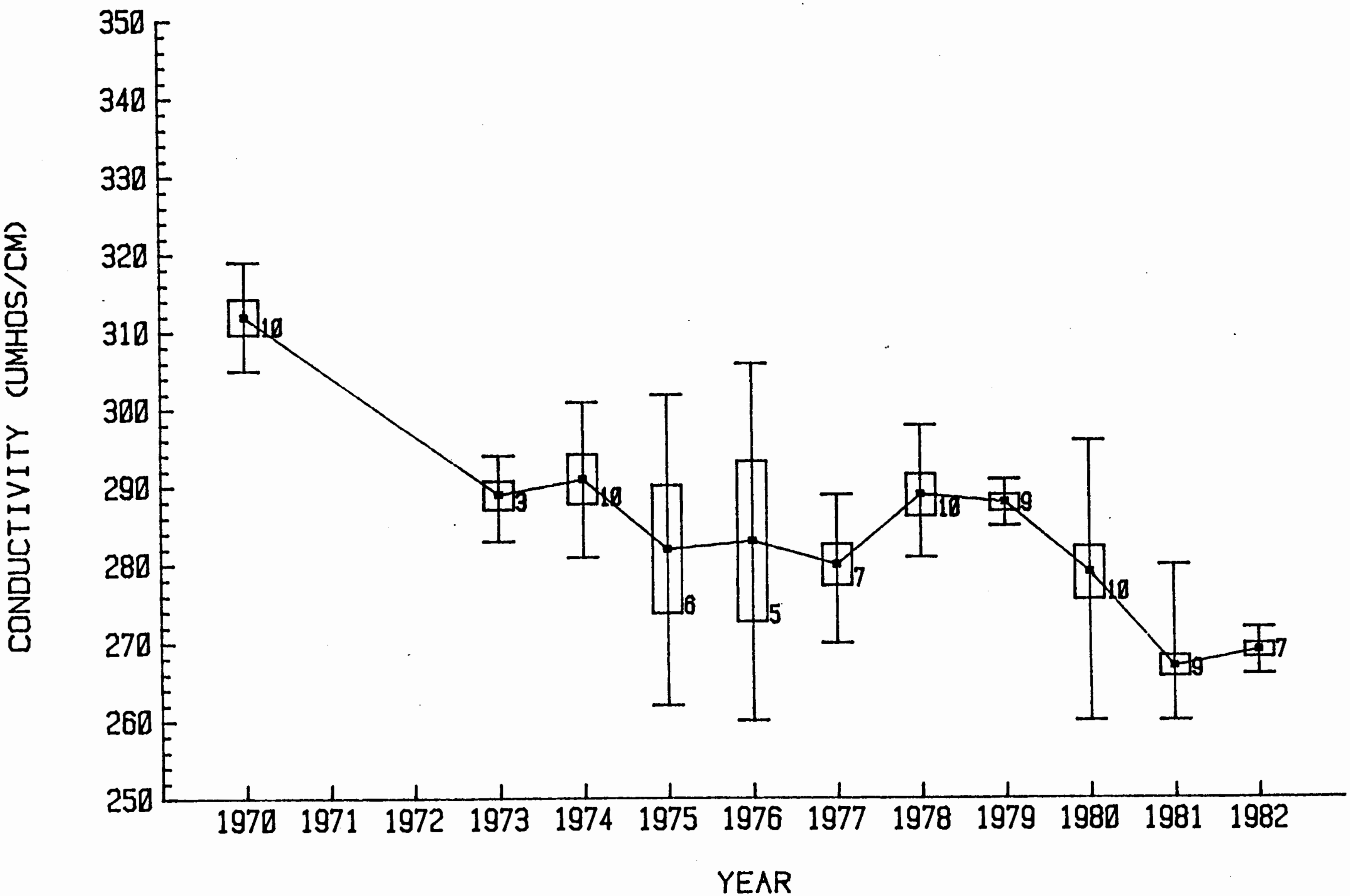


FIGURE 18. LAKE ERIE SPECIFIC CONDUCTANCE - CENTRAL BASIN

1978 MEAN CONCENTRATIONS

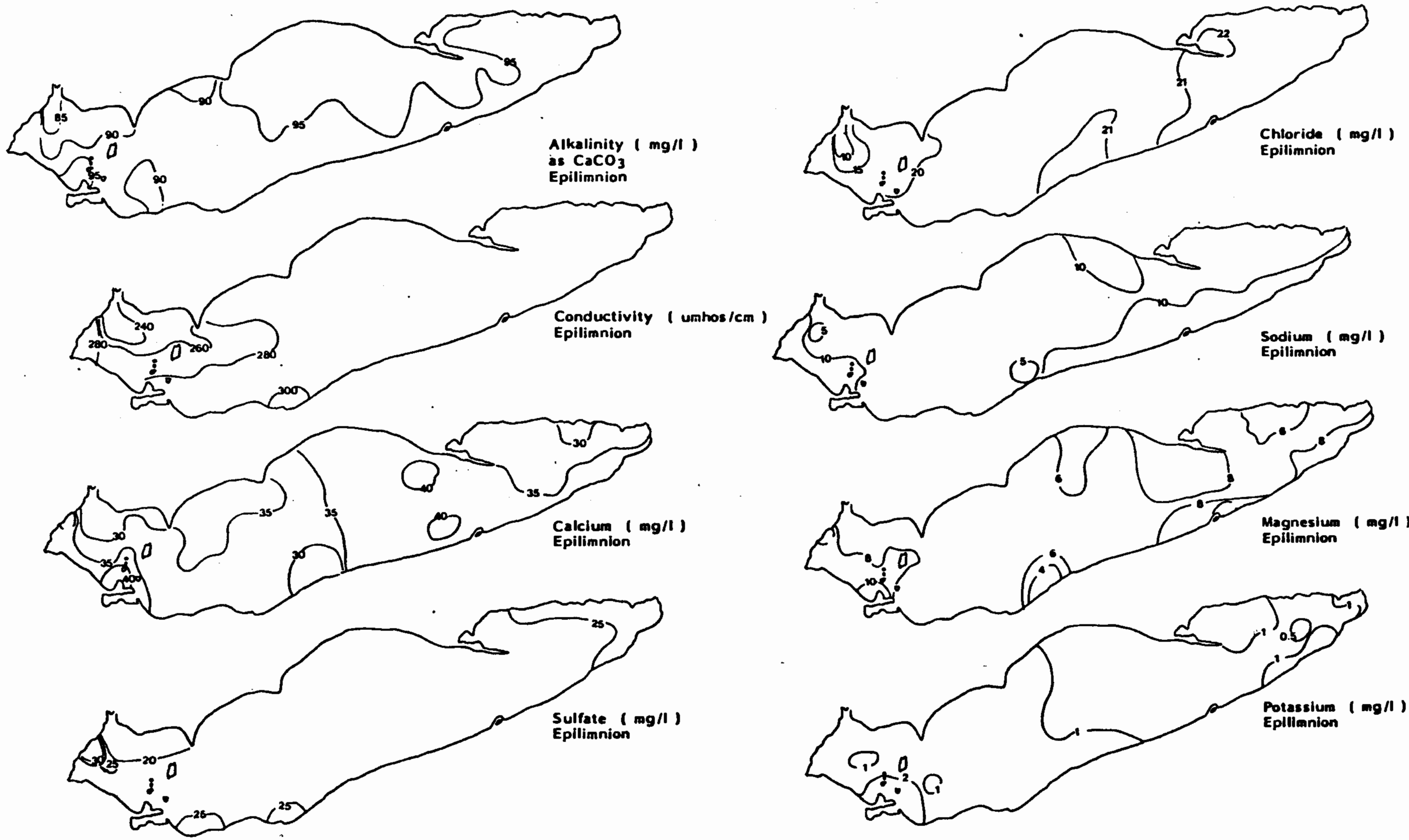


FIGURE 19. DISTRIBUTION OF MAJOR DISSOLVED SOLIDS IN LAKE ERIE

while data from the other three groups were from open lake stations, generally 5 km or more offshore. Annual mean values for 5-year periods are summarized below:

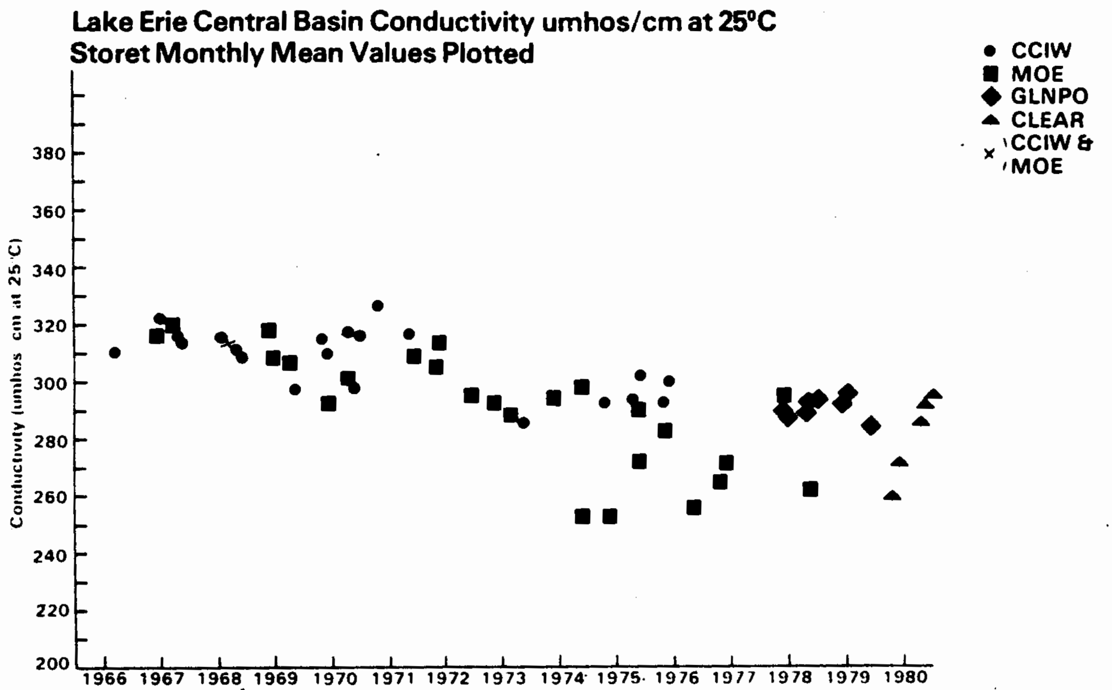
Dissolved Solids in Central Lake Erie

Period	Specific Conductance (umhos/cm + std error)	Chloride (mg/l + std error)	Sulfate (mg/l + std error)
1966-1970	313 + 1.8	24.0 + 0.5	24.3 + 0.8
1971-1975	298 + 7.0	21.6 + 0.8	22.7 + 0.4
1976-1980	284 + 2.8	19.4 + 0.3	22.5 + 0.4

Specific conductance data points on Figure 20 represent cruise mean values for periods of isothermal lake conditions (March-May and October-December). Conductivity thus indicates a rather slow decline for mean levels for the period of record. The mean value for 1976-1980 (284 umhos/cm) is approximately nine percent lower than the mean 1966-1970 value (313 umhos/cm). Trends in central basin chloride (Figure 20) shows a more noticeable decline from a mean concentration of 24.0 mg/l for 1966-1970 to 19.4 mg/l for 1976-1980. Sulfate concentrations showed no discernable trend.

Nutrients. Phosphorus has been identified as a limiting nutrient for algal productivity in Lake Erie (Hartley and Potos 1971), whereas nitrogen is in sufficiently large supplies in the waters of the lake that it is not considered a limiting nutrient. The status of both of these elements will be discussed in this section.

Annual mean concentrations for the western, central and eastern basins for the period 1970 to 1982 (Table 14) are presented in Figures 21, 22 and 23, respectively, and are summarized in 5-year periods below:



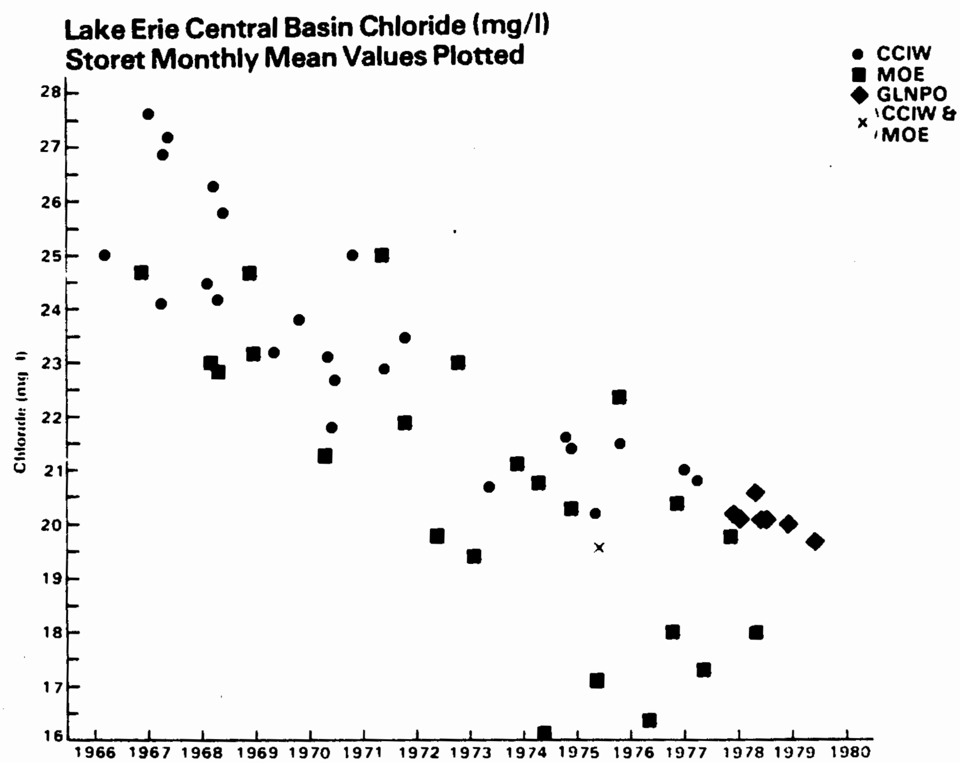


FIGURE 20. TRENDS IN LAKE ERIE SPECIFIC CONDUCTANCE AND CHLORIDE CONCENTRATION-CENTRAL BASIN

TABLE 14

LAKE ERIE TOTAL PHOSPHORUS CONCENTRATIONS

Year	Western Basin				Central Basin				Eastern Basin				Cruises (N)		
	Min (ug/l)	Max (ug/l)	Mean (ug/l)	Std Error (±)	Min (ug/l)	Max (ug/l)	Mean (ug/l)	Std Error (±)	Min (ug/l)	Max (ug/l)	Mean (ug/l)	Std Error (±)	W	C	E
1970	33.4	60.0	44.6	3.0	11.6	36.0	20.5	2.5	8.8	30.9	17.5	2.2	10	10	10
1973	21.7	48.4	34.7	6.9	14.3	25.6	18.5	3.6	11.8	68.8	31.1	11.3	3	3	4
1974	22.9	45.9	35.1	3.6	13.6	20.1	16.8	1.1	7.9	66.8	20.8	2.8	6	6	6
1975	32.4	56.6	42.3	3.5	14.6	31.7	20.3	2.8	14.1	42.9	27.6	4.1	6	6	5
1976	29.5	67.0	44.9	6.7	16.5	28.8	22.5	2.3	--	--	--	--	5	5	--
1977	33.9	53.3	40.7	6.3	12.2	33.1	24.1	3.1	13.0	22.9	18.3	2.1	3	7	4
1978	--	--	--	--	12.0	15.7	14.2	0.5	9.9	16.5	13.0	1.0	--	6	6
1979	19.1	98.0	33.9	8.2	10.0	18.4	13.4	0.9	5.2	18.6	10.8	2.4	9	8	5
1980	17.7	37.7	28.8	2.2	4.0	23.2	13.9	2.4	9.3	23.7	13.8	2.6	9	9	5
1981	24.1	55.3	36.7	3.1	13.4	26.0	19.0	1.4	--	--	--	--	9	9	--
1982	23.2	139.7	46.9	15.7	10.4	34.8	16.3	1.6	--	--	--	--	6	7	--

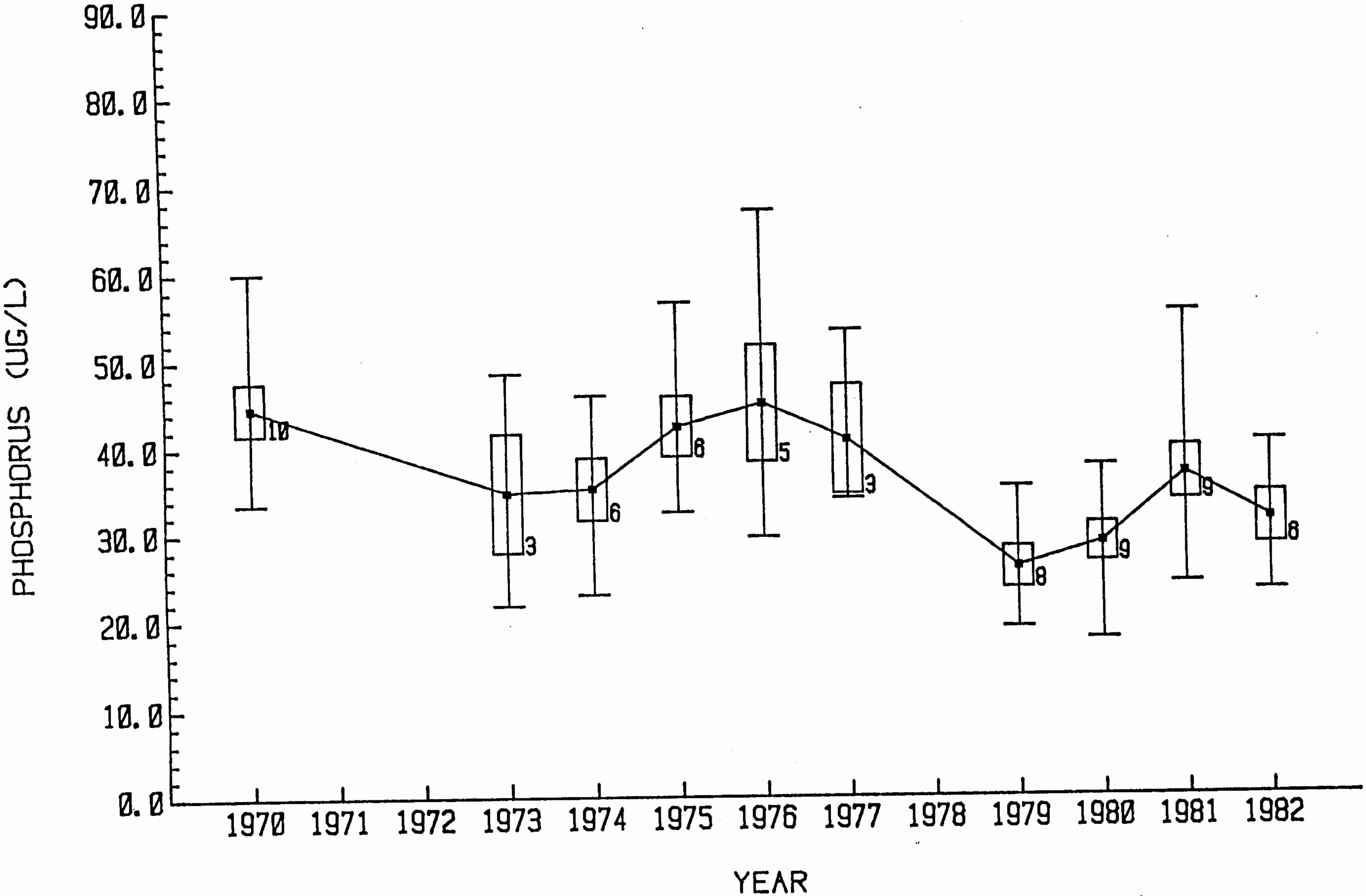


FIGURE 21. LAKE ERIE TOTAL PHOSPHORUS CONCENTRATION - WESTERN BASIN

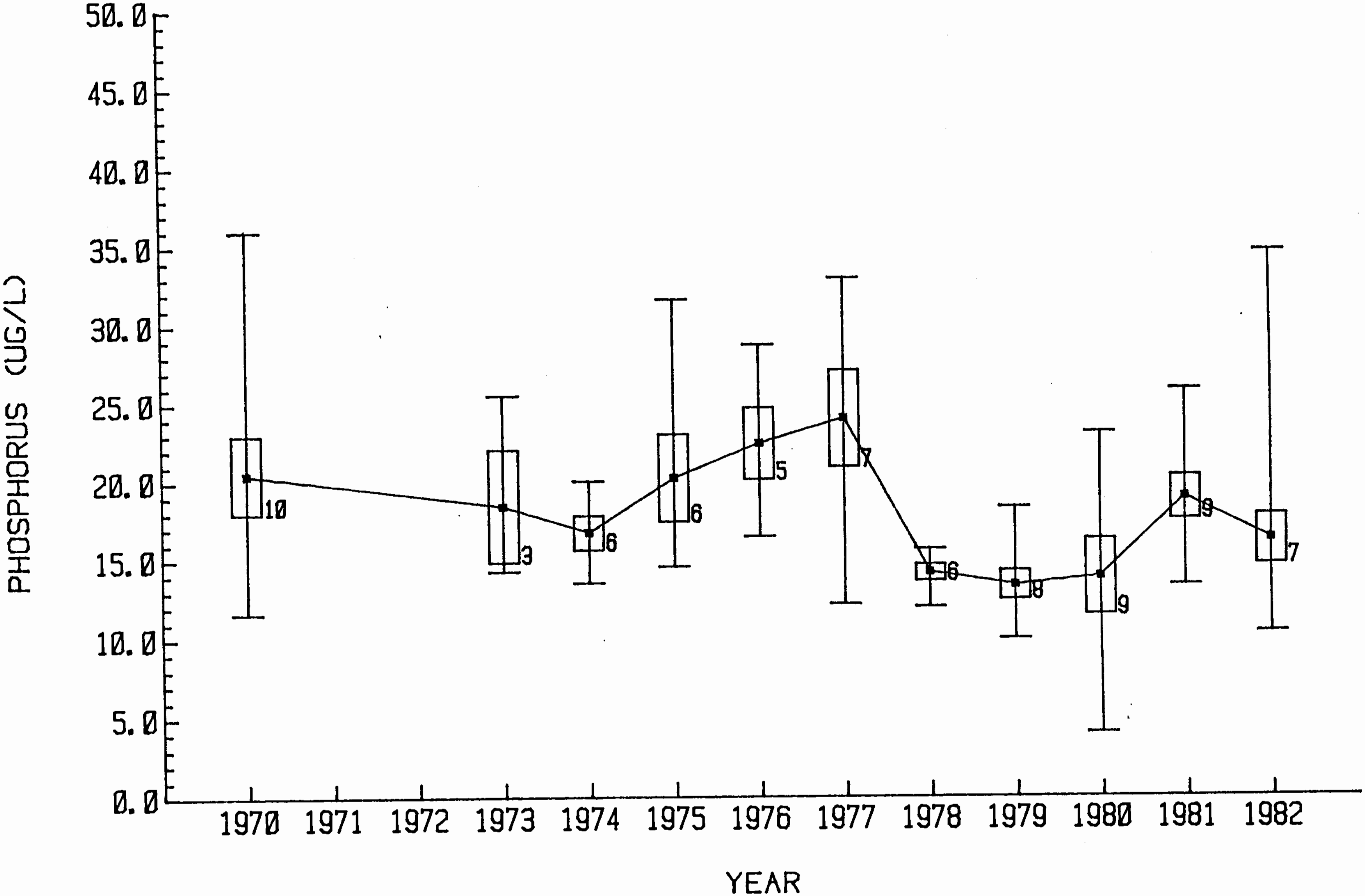


FIGURE 22. LAKE ERIE TOTAL PHOSPHORUS CONCENTRATION – CENTRAL BASIN

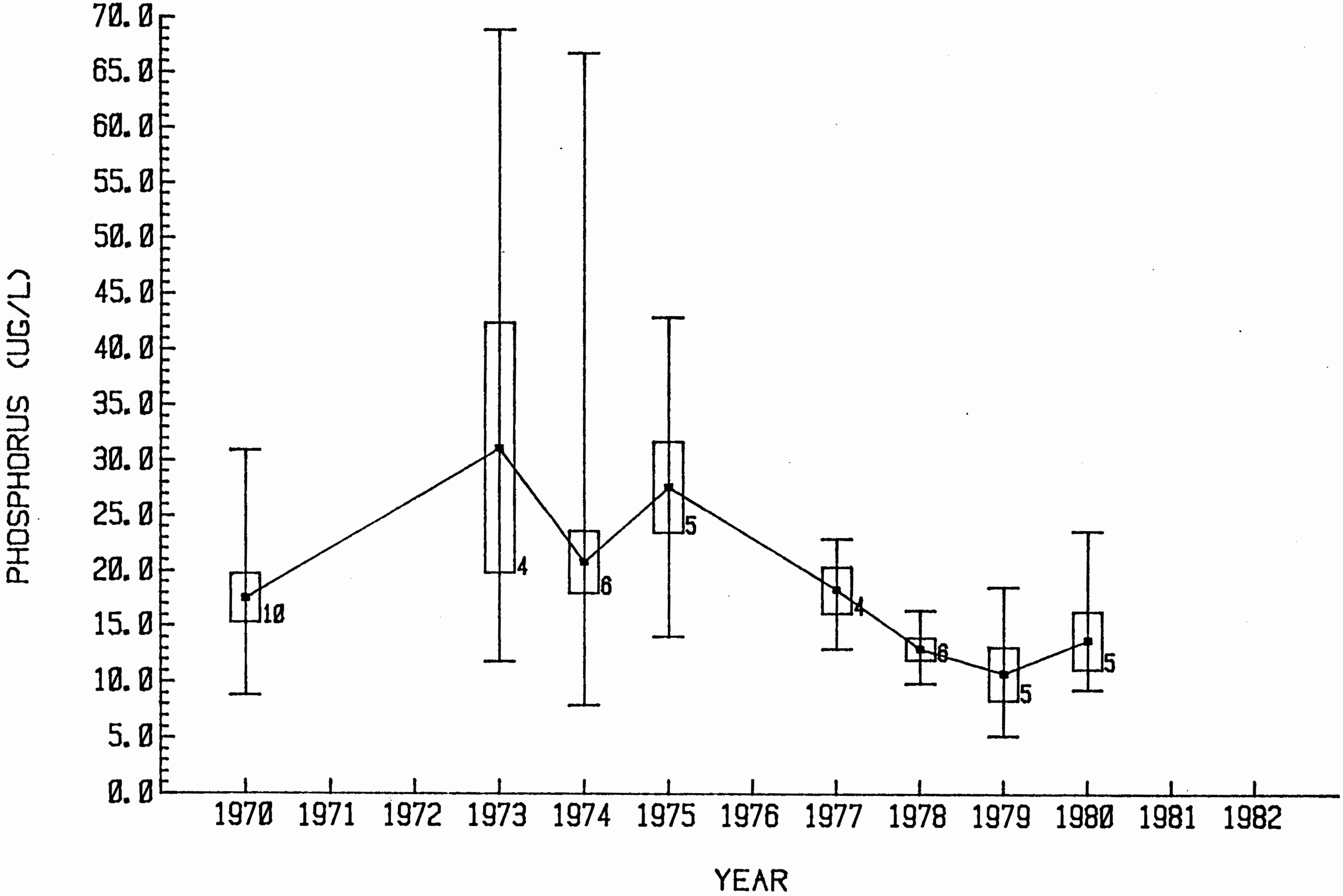


FIGURE 23. LAKE ERIE TOTAL PHOSPHORUS CONCENTRATION - EASTERN BASIN

Total Phosphorus Concentrations in Lake Erie

Period	Western Basin (ug/l ± std error)	Central Basin (ug/l ± std error)	Eastern Basin (ug/l ± std error)
1970-1974	38.1 ± 3.2	18.6 ± 1.1	23.1 ± 4.1
1975-1979	40.5 ± 2.3	18.9 ± 2.2	17.4 ± 4.3
1980-1982	37.5 ± 5.2	16.4 ± 1.5	13.8 ± 2.6

The western basin has a significantly higher concentration than the other two basins by a factor of over two, but no statistically significant changes in concentrations occurred since 1970. However, a slight decline is suspected for the latter half of the 1970s when spring storm values are excluded from the annual means, as has been done in Figure 21 for the shallow western basin.

The distribution of most nutrients throughout the lake shows similar patterns. Total phosphorus, for example is characterized by high concentrations near the mouth of the Maumee River in the western basin (Figure 24) and the Cuyahoga River in the central basin (Figure 25). The impact of hypolimnetic regeneration of phosphorus in both central and eastern basins is also illustrated in Figure 25. There is a general west-to-east decrease with highest values located along the United States shore, particularly at the mouths of major tributaries. The Detroit River is an exception in that a large volume of upper Great Lakes water tends to dilute the nutrient load contributed by the urban and industrial complex adjacent to the river. Although low in concentration when compared to the Maumee River, the Detroit River in 1980 contributed approximately 37% of the total load of phosphorus to Lake Erie (Table 15), whereas the Maumee River accounted for about 12% of the total load.

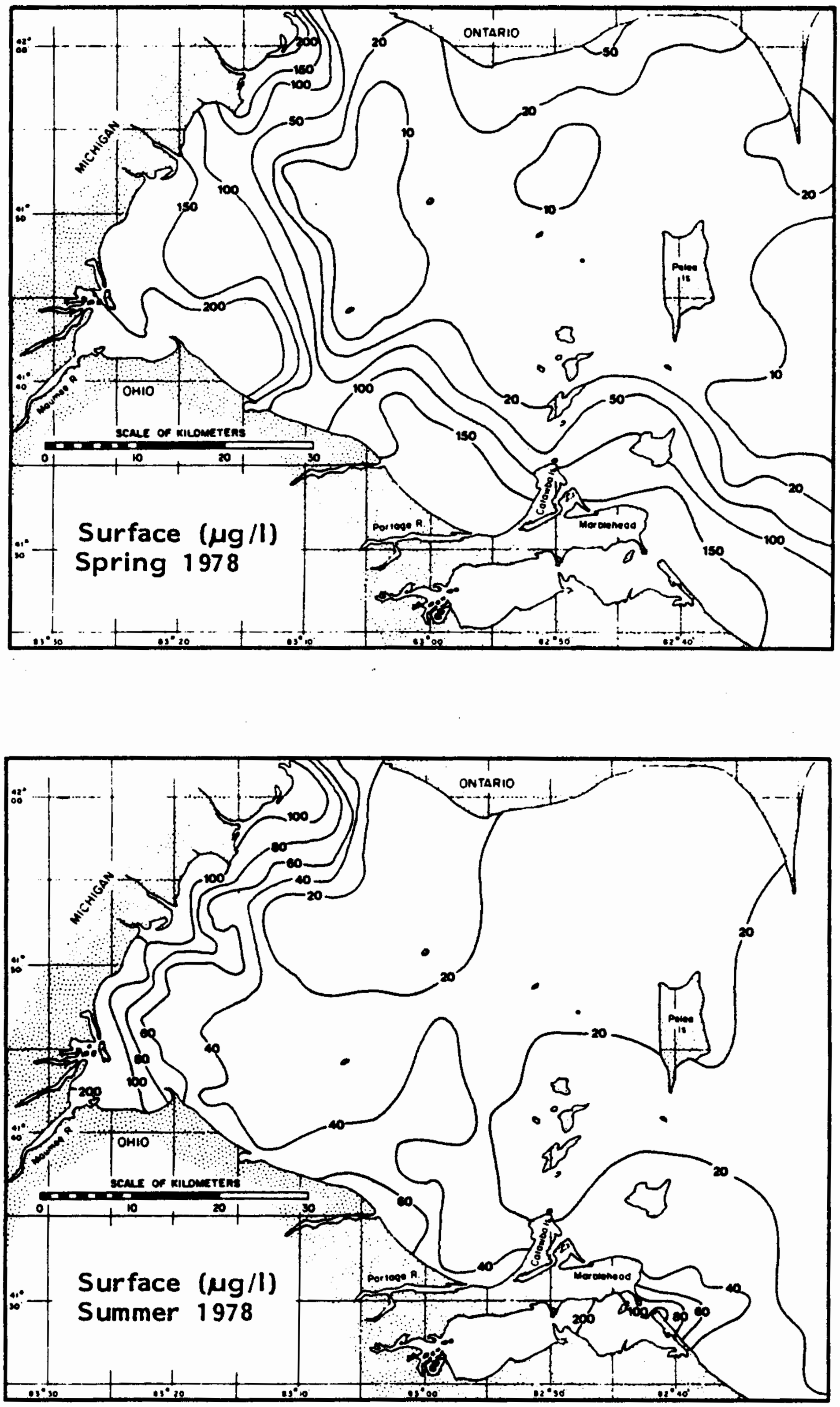


FIGURE 24. DISTRIBUTION OF TOTAL PHOSPHORUS IN LAKE ERIE-WESTERN BASIN

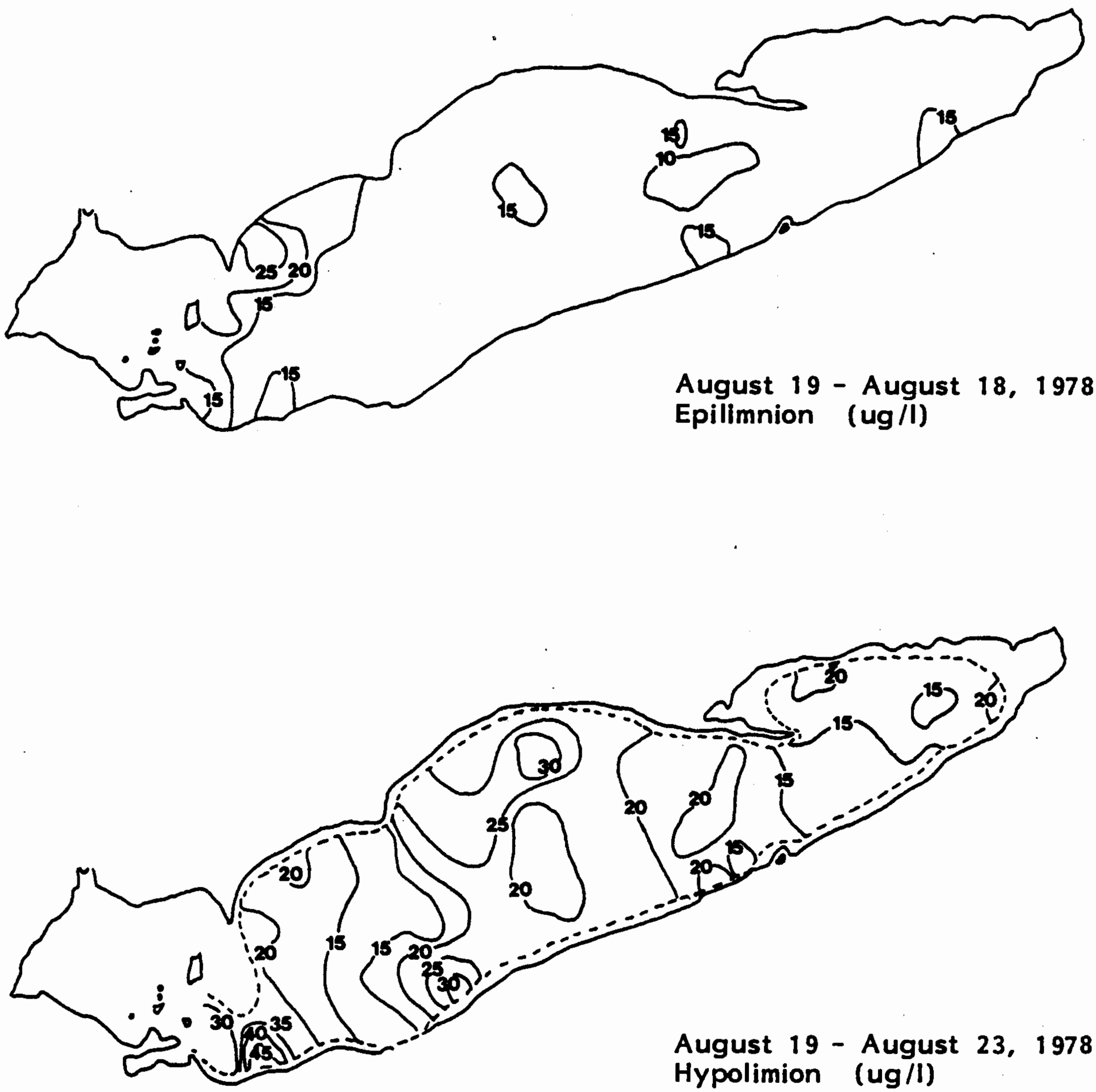


FIGURE 25. DISTRIBUTION OF TOTAL PHOSPHORUS IN THE CENTRAL AND EASTERN BASINS OF LAKE ERIE.

TABLE 15

ESTIMATES OF TOTAL PHOSPHORUS LOADING TO LAKE ERIE

Year	Detroit River Loading To Lake Erie (Metric Tons)			Loading to Entire Lake (Metric Tons)		
	IJC	CCIW	USACOE	IJC	CCIW	USACOE
1967		14,309			23,437	
1968	32,850	17,822			27,944	
1969	26,280	17,389			26,977	
1970	25,915	15,422	10,488	23,500	23,724	20,448
1971	15,330	10,436	12,064	18,033	18,077	20,396
1972	14,600	12,000	11,633	22,000	22,271	25,726
1973	16,425	10,548	13,169	19,910	20,485	24,113
1974	11,315	8,492	11,422	18,263	16,821	22,605
1975	12,045	6,521	10,366	13,802	14,534	20,268
1976	10,220	7,991	10,065	15,416	15,831	20,041
1977	6,205	4,150	8,317	14,560	11,229	20,499
1978	6,205	4,150	6,206	19,464	13,894	15,336
1979	5,110		5,450	11,941		14,650
1980	4,745		5,212	14,855		12,141

Data Sources:
IJC (1981)
Frazer and Willson (1981)
USACOE, Buffalo District (1982)

Nutrient distributions in the nearshore waters correspond to major loadings source. Tributary mouths in the western basin and south shore of the central basin are characterized by high concentrations of phosphorus throughout the year (Figure 26). Other notable locations for high concentrations include the mouth of the Grand River (Ontario) and adjacent to Erie, Pennsylvania, both in the eastern basin (nearshore reach nos. 2 and 19, respectively).

Estimates of total phosphorus loading to Lake Erie have been published by several agencies. These estimates vary considerably which has led to some confusion in relating the trend of "in-lake" concentrations to changes in the load being delivered to the lake. Table 15 provides a comparison of the loading estimates generated by IJC, NWRI/CCIW, and USACOE for the period 1967-1980. Estimates from all sources, except shoreline erosion, are compared graphically in Figure 27 and from only the Detroit River in Figure 28. All estimates show a decided decrease in the load of total phosphorus to the lake. The mean annual decline for all three agencies was found to be 779 $\pm$ 12 metric tons. In the 10-year period from 1971 to 1980, the contribution of the Detroit River to the total amount of phosphorus loaded to Lake Erie has fallen from 67% to 37%.

It has not been possible to translate the decline in phosphorus loading to Lake Erie to decreases in the concentrations or quantities of total phosphorus measured in the lake. Even when open lake data is filtered to remove the erratic fluctuations caused by spring and fall storms (Figure 29) no significant changes in central basin total phosphorus can be seen from 1970 to 1982. In fact, total phosphorus increased in minimum summer quantities for the period 1970 to 1976 (Figure 30). This can be partially explained by phosphorus releases from sediment through wave resuspension and anoxic regeneration. Several investigations have demonstrated that approximately 80% of the phosphorus loading to Lake Erie becomes incorporated into the bottom sediments (Burns 1976 and Herdendorf 1980). Cruise data for 1978-1980 suggest a response to decreasing phosphorus loading with lower summer minima and annual quantities; however, 1981 and 1982 data show very similar values to the mid-1970s. If improvements are to be detected in the lake they should show up first in the western basin where the greatest decrease in loading has occurred. Figure 31 may illustrate such a trend for the Ontario shore adjacent to the mouth of the Detroit River. The

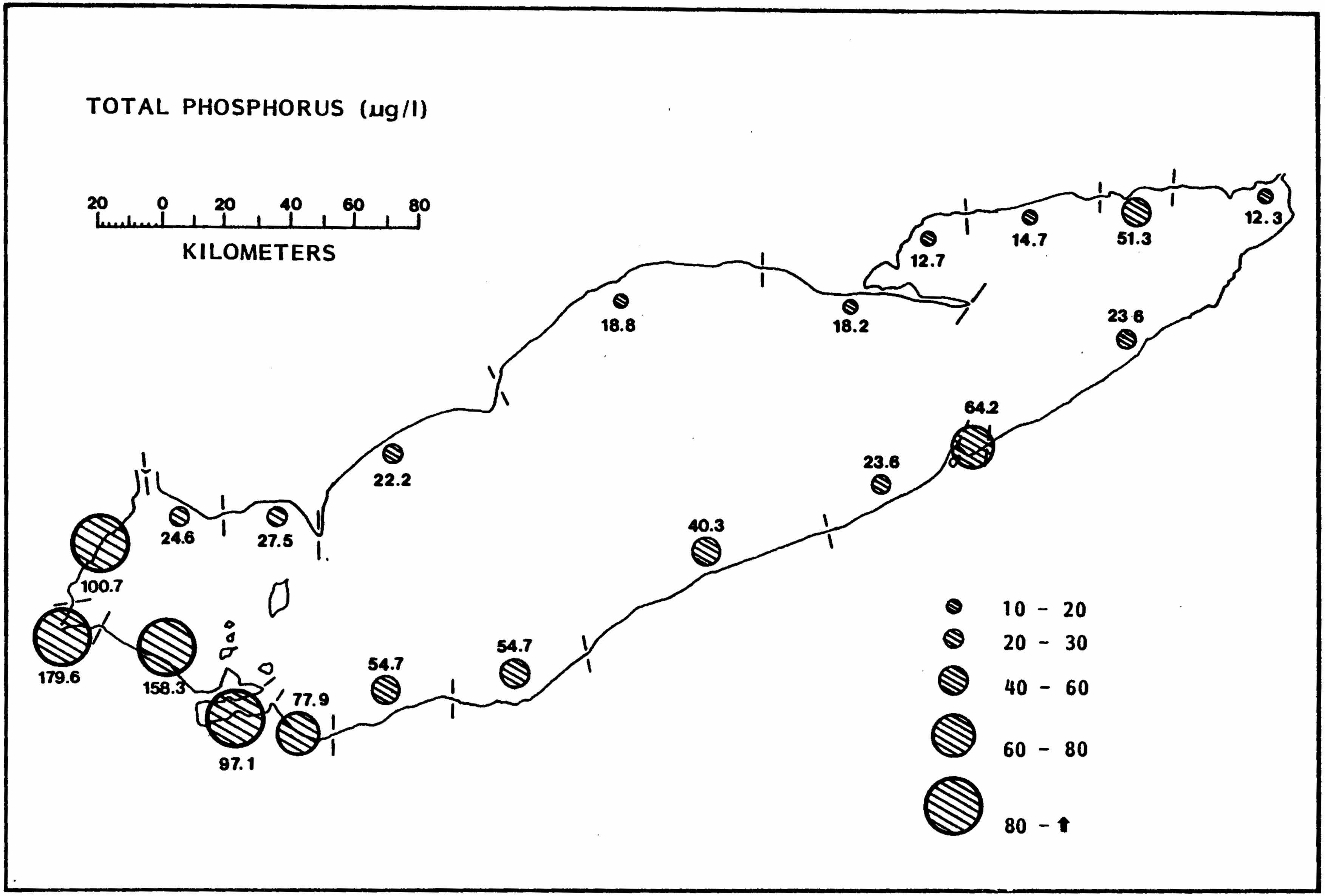


FIGURE 26. MEAN NEARSHORE CONCENTRATIONS OF TOTAL PHOSPHORUS (1978-1979)

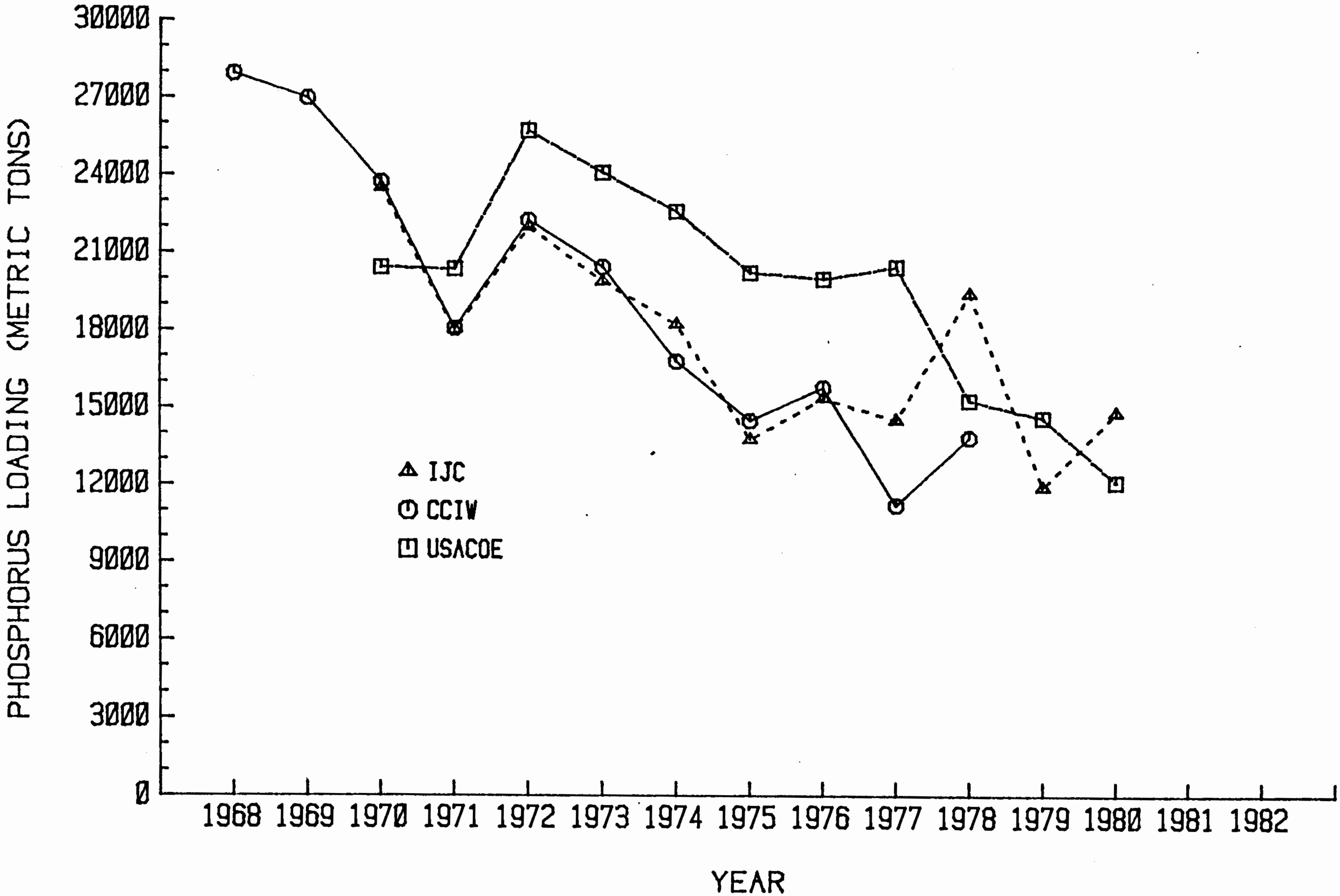


FIGURE 27. COMPARISON OF TOTAL PHOSPHORUS LOADING ESTIMATES TO LAKE ERIE

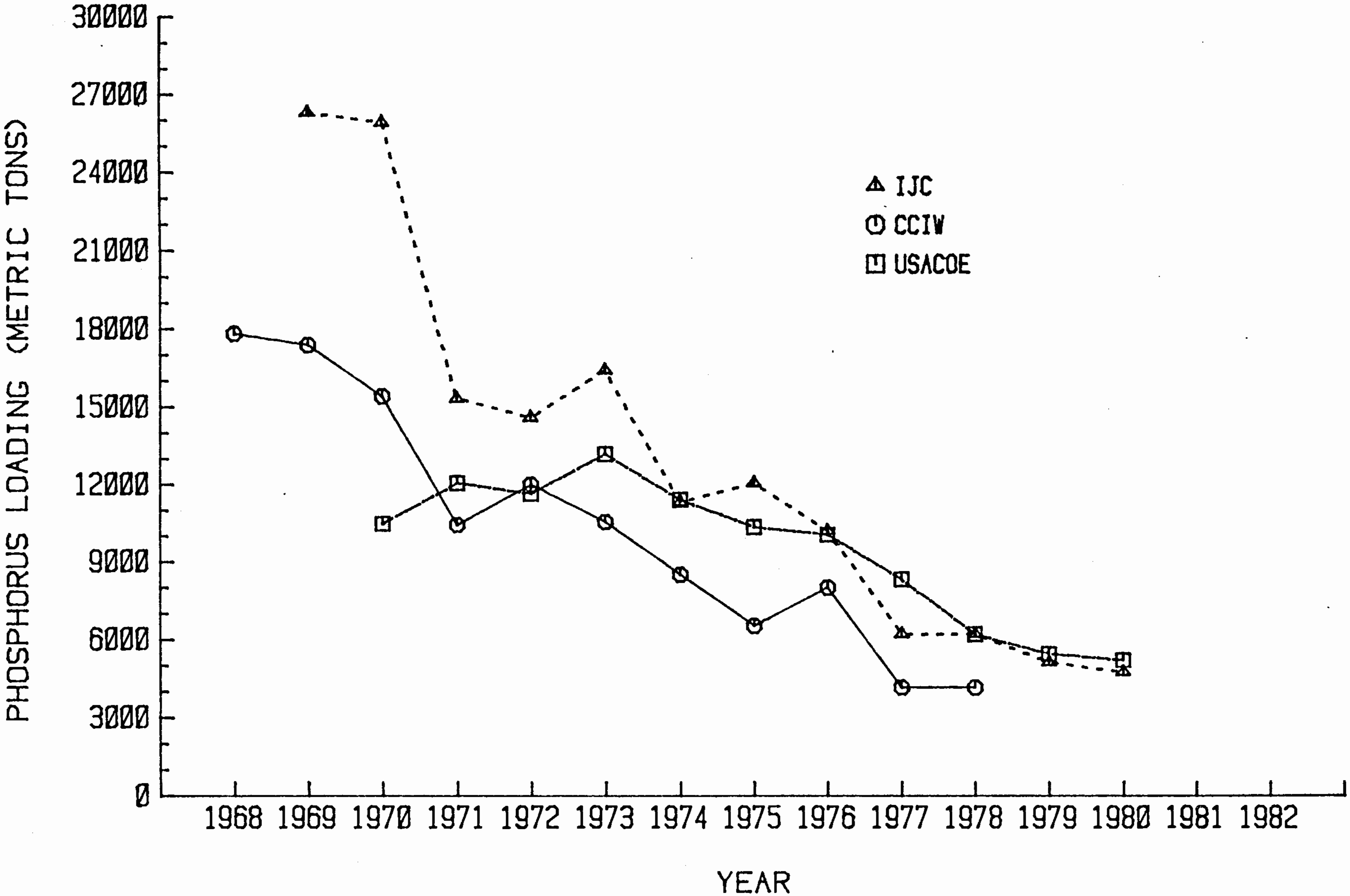


FIGURE 28. COMPARISON OF DETROIT RIVER TOTAL PHOSPHORUS LOADING ESTIMATES TO LAKE ERIE

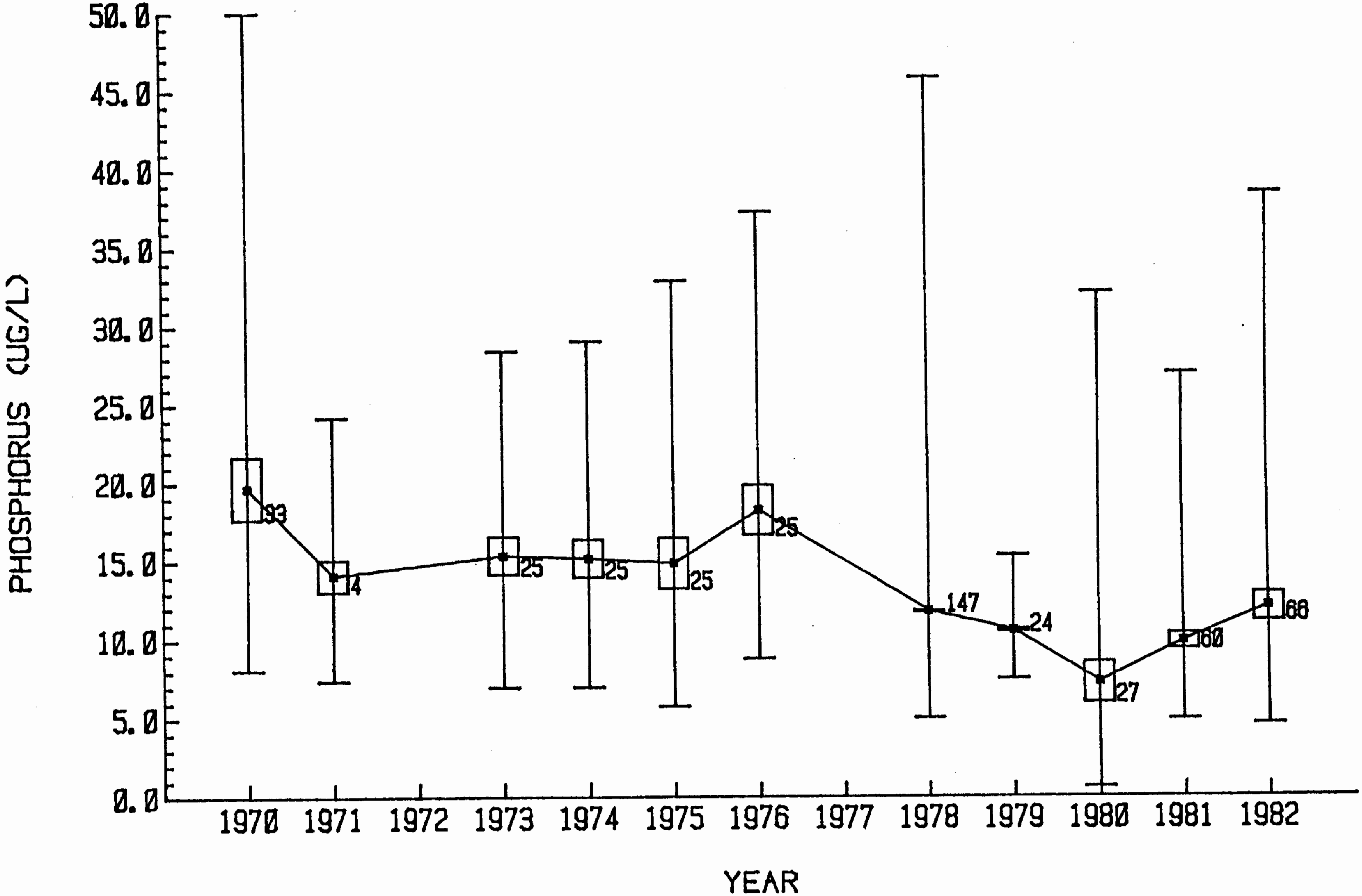


FIGURE 29. LAKE ERIE TOTAL PHOSPHORUS CONCENTRATION - EARLY SUMMER EPILIMNION FOR CENTRAL BASIN

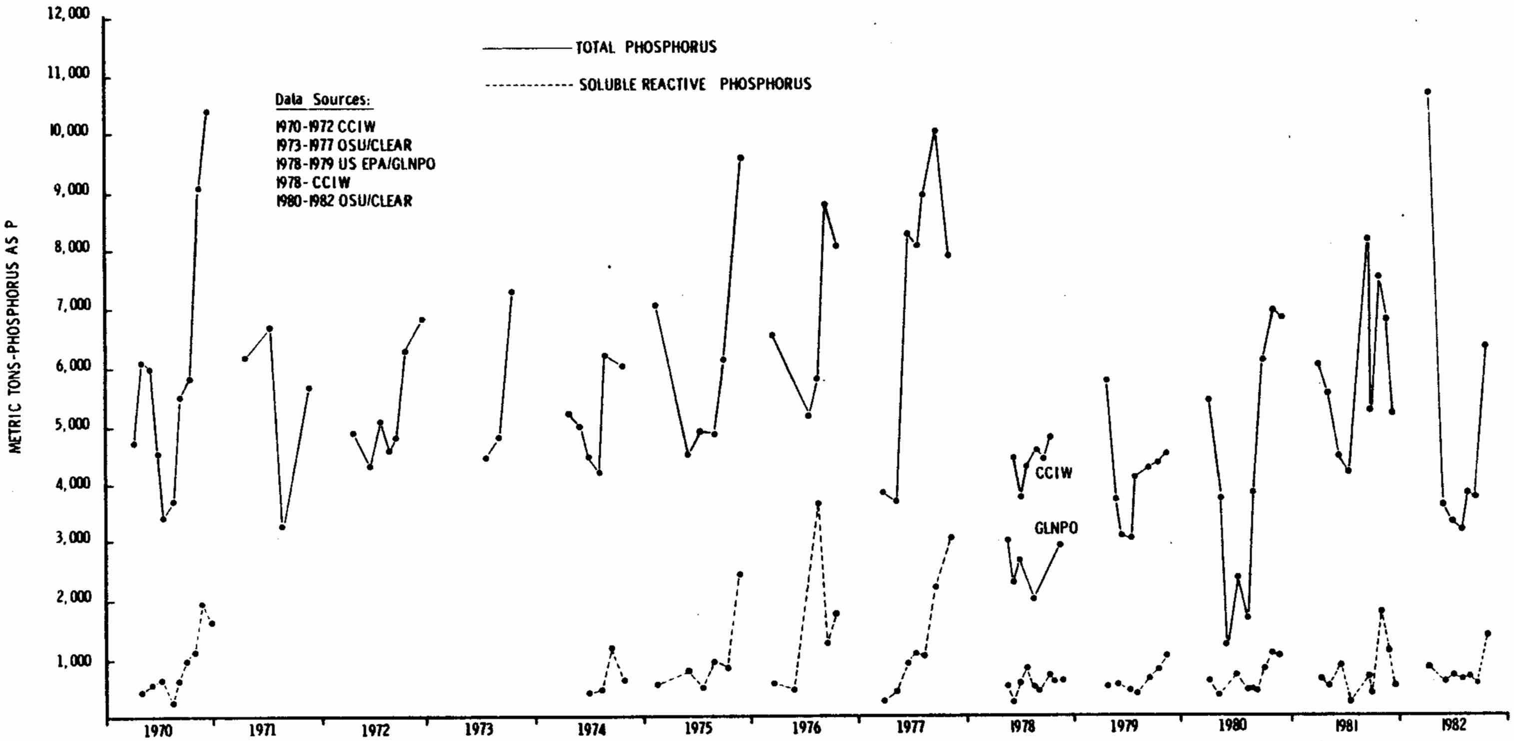


FIGURE 30. PHOSPHORUS QUANTITIES IN LAKE ERIE-CENTRAL BASIN

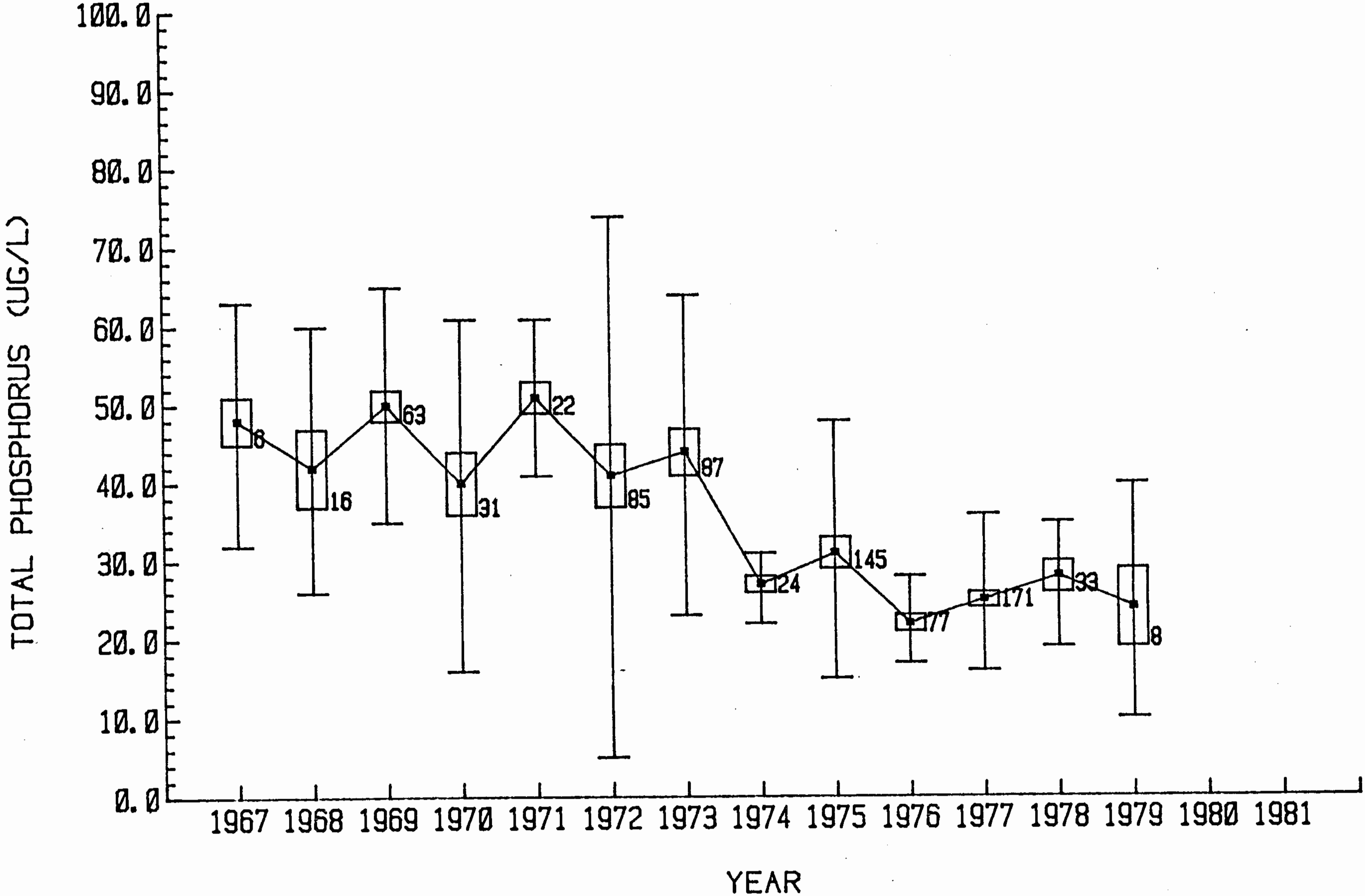


FIGURE 31. LAKE ERIE TOTAL PHOSPHORUS CONCENTRATION - WESTERN BASIN ONTARIO NEARSHORE TREND

Ontario Ministry of Environment has determined that the concentration of total phosphorus in these nearshore waters has decreased approximately 40% in the 10-year period from 1970 to 1979 which is comparable to the improvements indicated for the Detroit River in Table 15.

Nitrogen is the only major dissolved constituent in the waters of Lake Erie which has shown a dramatic increase in the past decade. Increased use of chemical fertilizers and gaseous emissions of nitrogen compounds within the drainage basin are thought to be the major causes. Nitrate plus nitrite loading to the lake has increased significantly during the period of record (1967 to 1979). Loading from the Detroit River alone averaged 160 metric tons per day in 1979, more than twice the amount reported for 1967. Lake concentrations have also increased significantly for nitrate plus nitrite nitrogen since the first comprehensive surveys in the mid-1960s. Open lake concentrations in the western basin for 1963-1965 averaged 120 ug/l while the central and eastern basins averaged 90 ug/l (FWPCA 1968a). Concentrations for the period 1978-1982 averaged 434 ug/l for the western basin and 176 ug/l for the central and eastern basins (Table 16). Trends for the western and central basin are illustrated in Figures 32 and 33, respectively, and are summarized below for all three basins:

Nitrate + Nitrite Concentrations in Lake Erie

Period	Western Basin (ug/l ± std error)	Central Basin (ug/l ± std error)	Eastern Basin (ug/l ± std error)
1963-1965	120	90	90
1970-1975	259 ± 24	121 ± 21	113 ± 12
1978-1982	434 ± 104	178 ± 22	172 ± 8

TABLE 16

LAKE ERIE NITRATE + NITRITE CONCENTRATIONS

Year	Western Basin Min (ug/l)	Western Basin Max (ug/l)	Western Basin Mean (ug/l)	Western Basin Std Error (±)	Central Basin Min (ug/l)	Central Basin Max (ug/l)	Central Basin Mean (ug/l)	Central Basin Std Error (±)	Eastern Basin Min (ug/l)	Eastern Basin Max (ug/l)	Eastern Basin Mean (ug/l)	Eastern Basin Std Error (±)	Cruises (N) W	Cruises (N) C	Cruises (N) E
1963-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1965	--	--	120	--	--	--	90	--	--	--	90	--	--	--	--
1970	53	465	213	47	18	135	79	13	57	172	113	12	10	10	10
1973	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1974	111	644	275	82	46	263	142	30	--	--	--	--	6	6	--
1975	129	575	290	66	101	195	142	15	--	--	--	--	6	6	--
1976	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1977	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1978	42	727	290	86	88	238	168	22	156	232	180	11	8	7	7
1979	98	796	368	101	68	163	120	12	117	210	164	12	8	8	8
1980	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1981	430	1,149	742	98	143	369	220	24	--	--	--	--	9	9	--
1982	107	625	336	87	124	307	205	25	--	--	--	--	7	7	--

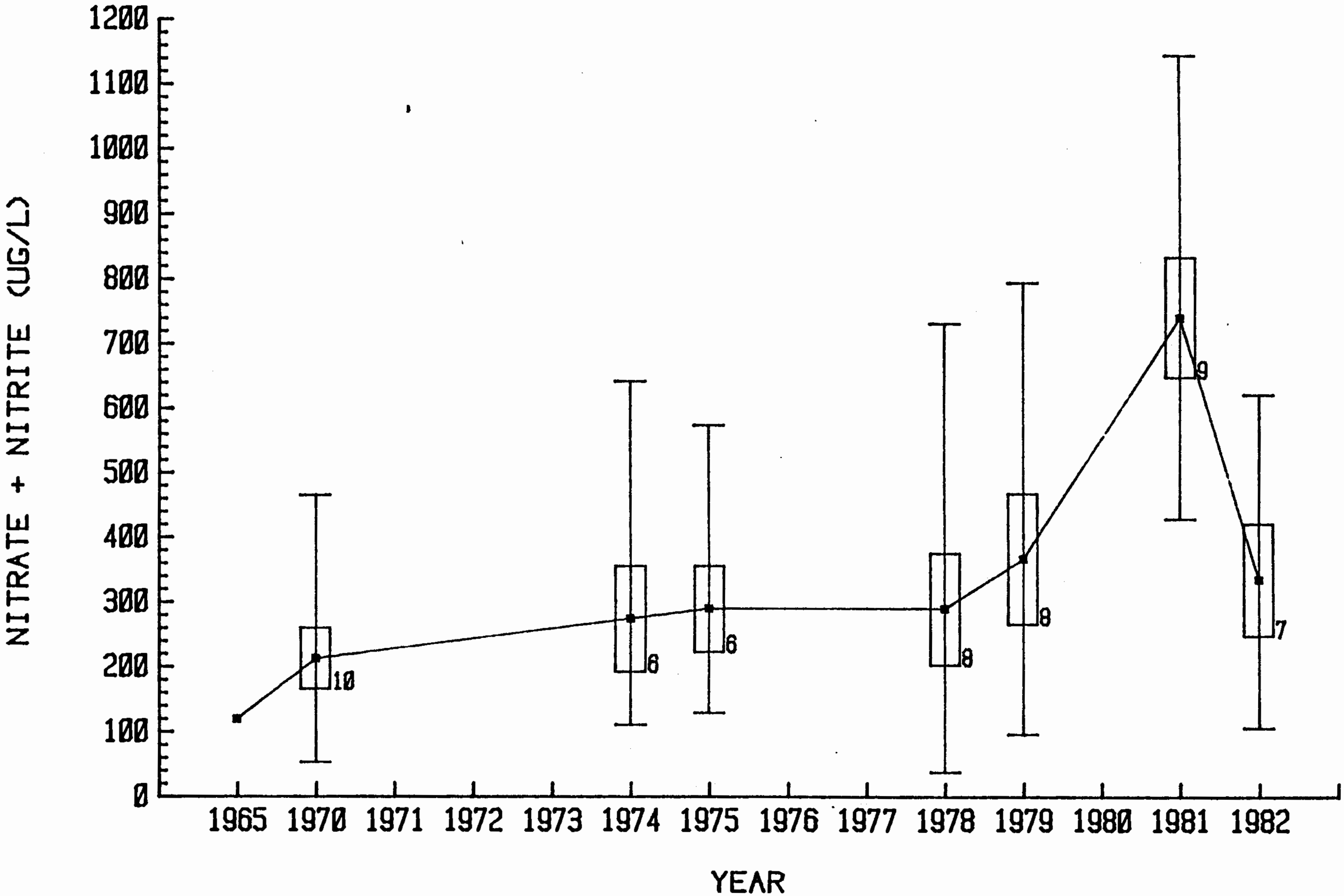


FIGURE 32. LAKE ERIE NITRATE + NITRITE CONCENTRATIONS - WESTERN BASIN

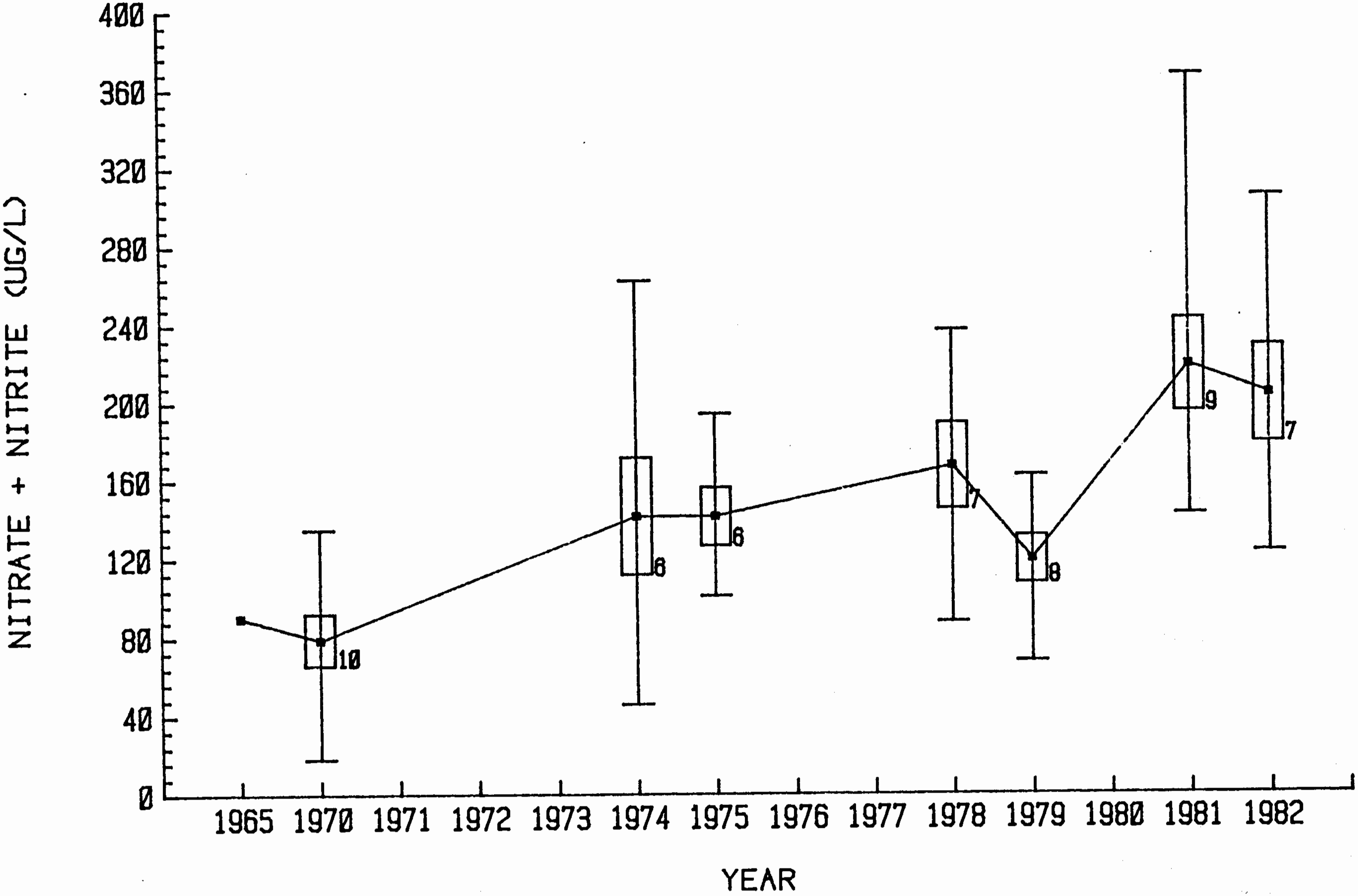


FIGURE 33. LAKE ERIE NITRATE + NITRITE CONCENTRATION - CENTRAL BASIN

Chlorophyll and algal biomass. Chlorophyll pigment serves as a useful indicator of algal productivity in Lake Erie. Annual mean concentrations of corrected chlorophyll a for the period 1970 to 1982 are presented in Table 17 and shown graphically for the western, central and eastern basin on Figures 34, 35 and 36, respectively. Like phosphorus no significant trend in chlorophyll concentrations can be ascertained for the entire period. However, when summarize in 5-year periods a recent decline is apparent:

Chlorophyll a Concentrations in Lake Erie

Period	Western Basin (ug/l ± std error)	Central Basin (ug/l ± std error)	Eastern Basin (ug/l ± std error)
1970-1974	10.9 ± 1.4	4.4 ± 0.1	4.5 ± 0.6
1975-1979	12.1 ± 0.5	5.1 ± 0.3	3.1 ± 0.2
1980-1982	8.4 ± 0.3	3.9 ± 0.5	1.9 ± 0.4

In all three basins, the period 1980 to 1983 is significantly lower in concentrations than the preceeding 5-year period, with the largest decrease occurring in the western basin. Again, if improvements are to be detected, they would first be expected in the western basin.

Typical spring and summer distributions of chlorophyll a in western Lake Erie are shown in Figure 37. Concentrations are generally the highest along the western and southern shores while the lowest values are found in the water mass influence by the Detroit River flow, particularly in spring, and along the north shore. In the central and eastern basins (Figure 38) concentrations are less than half those in the western basin yielding a strong gradient east of the islands region. The south shore commonly has the highest concentrations except in autumn when mid-lake concentrations can be highest as a result of nutrients being carried to surface following turnover.

TABLE 17

LAKE ERIE CHLOROPHYLL A CONCENTRATIONS

Year	Western Basin Min (ug/l)	Western Basin Max (ug/l)	Western Basin Mean (ug/l)	Western Basin Std Error (±)	Central Basin Min (ug/l)	Central Basin Max (ug/l)	Central Basin Mean (ug/l)	Central Basin Std Error (±)	Eastern Basin Min (ug/l)	Eastern Basin Max (ug/l)	Eastern Basin Mean (ug/l)	Eastern Basin Std Error (±)	Cruises (N) W	Cruises (N) C	Cruises (N) E
1970	3.3	19.3	8.6	2.7	2.5	9.2	4.5	0.7	1.4	5.4	3.3	0.4	10	10	10
1973	8.3	12.0	10.7	1.2	2.4	7.9	4.6	1.7	2.8	6.6	5.1	0.9	3	3	4
1974	8.8	17.1	13.4	1.4	2.4	9.4	4.2	1.1	3.3	7.1	5.1	0.5	6	6	6
1975	4.7	21.1	13.7	2.4	2.7	10.0	5.9	1.1	2.5	5.9	3.6	0.6	6	6	5
1976	6.4	16.9	12.4	2.1	2.5	8.5	5.2	1.1	--	--	--	--	5	5	--
1977	6.5	15.1	10.8	4.3	2.3	6.0	4.0	0.5	2.0	4.4	3.0	0.5	2	7	6
1978	5.2	17.8	12.5	1.5	2.9	8.3	5.2	0.7	1.7	5.4	3.2	0.5	8	8	8
1979	4.6	17.5	11.5	1.7	2.5	7.9	5.1	0.6	1.4	3.9	2.7	0.4	7	7	5
1980	4.2	12.8	8.4	1.0	1.5	4.6	3.1	0.3	1.2	3.6	1.9	0.4	9	10	6
1981	4.5	13.0	8.3	0.8	2.1	7.1	4.9	1.5	--	--	--	--	9	9	--
1982	3.1	16.7	8.4	2.1	1.5	5.6	3.7	0.6	--	--	--	--	7	7	--

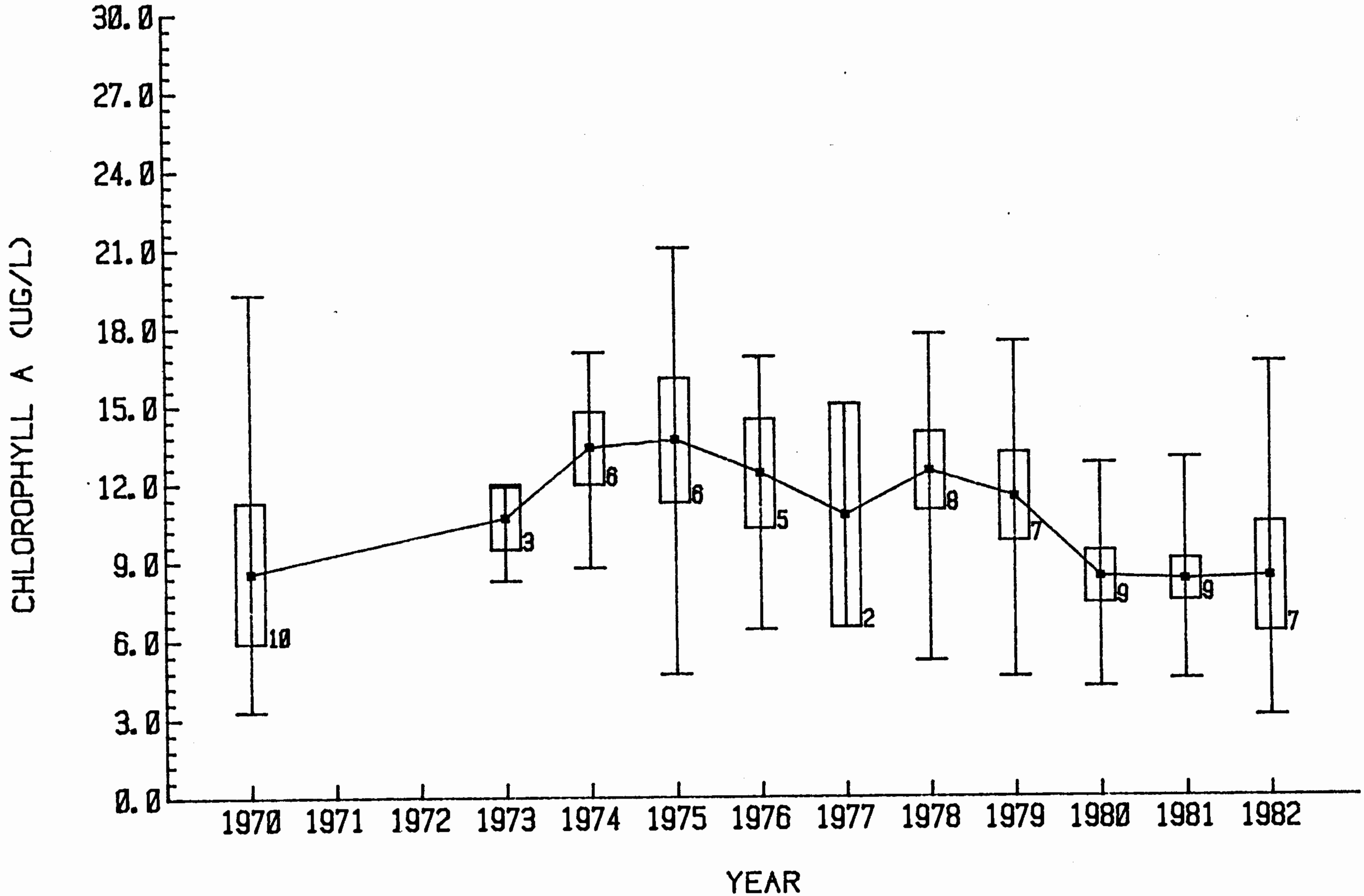


FIGURE 34. LAKE ERIE CHLOROPHYLL A CONCENTRATION - WESTERN BASIN

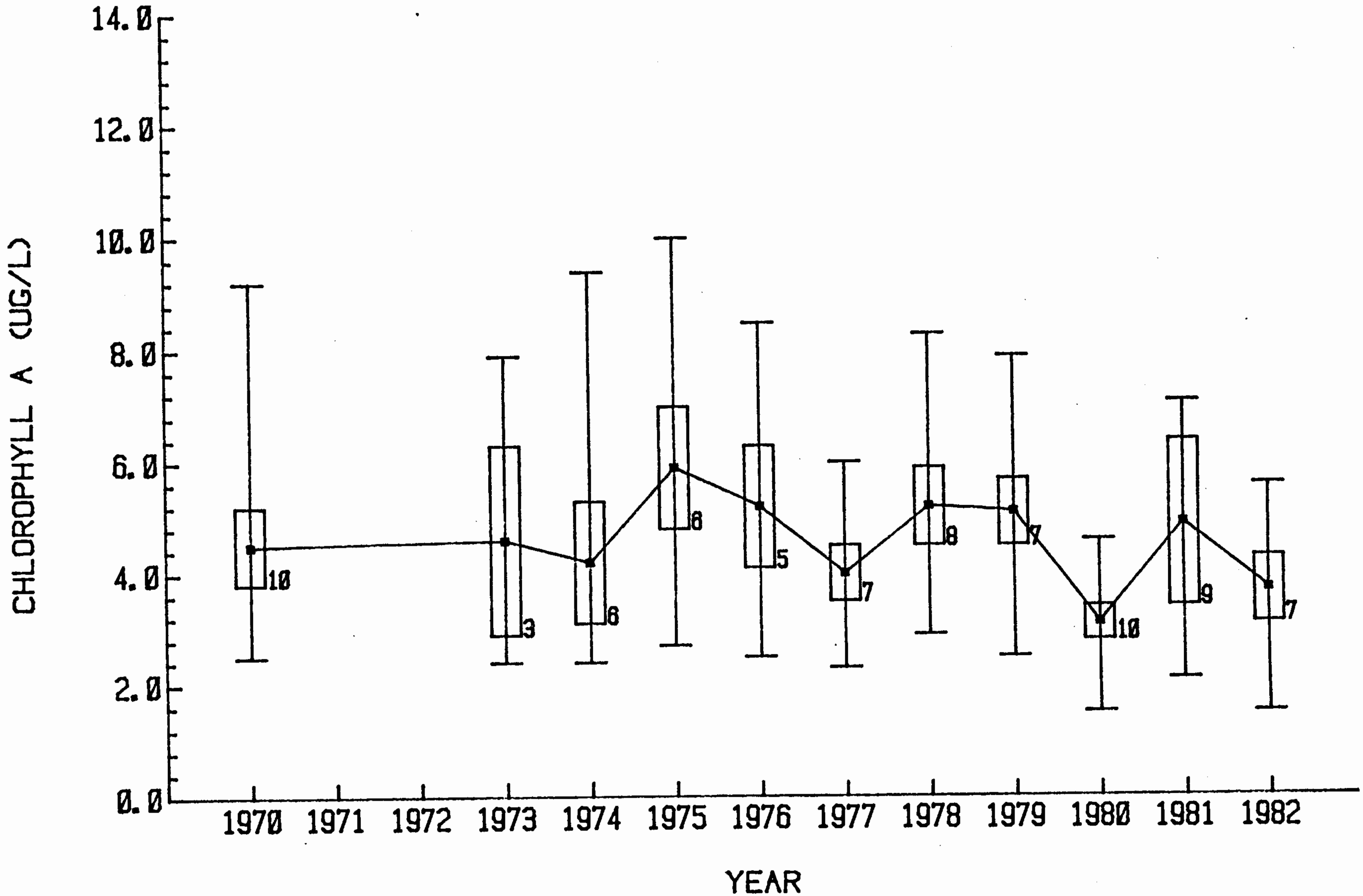


FIGURE 35. LAKE ERIE CHLOROPHYLL A CONCENTRATION - CENTRAL BASIN

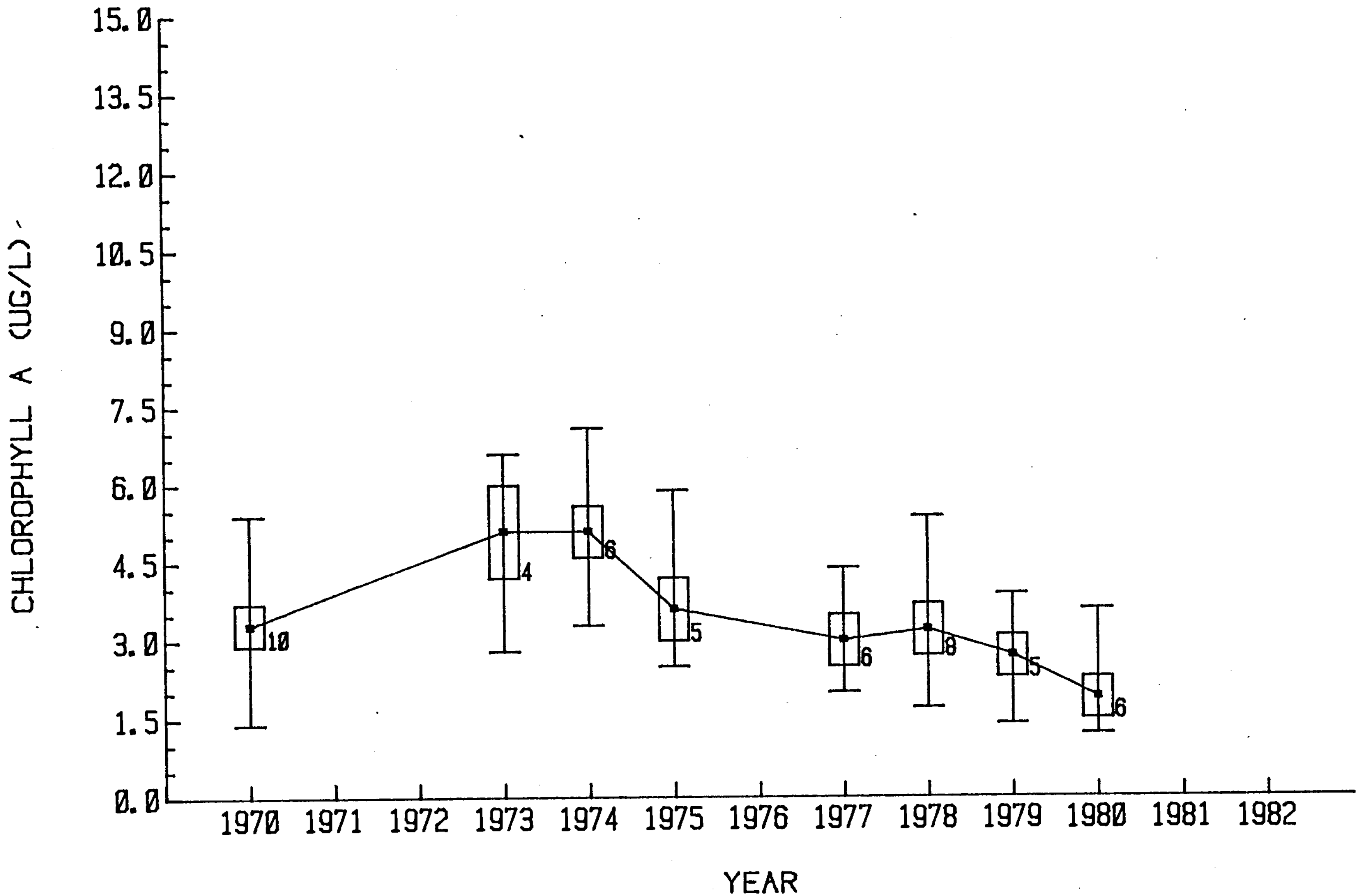


FIGURE 36. LAKE ERIE CHLOROPHYLL A CONCENTRATION - EASTERN BASIN

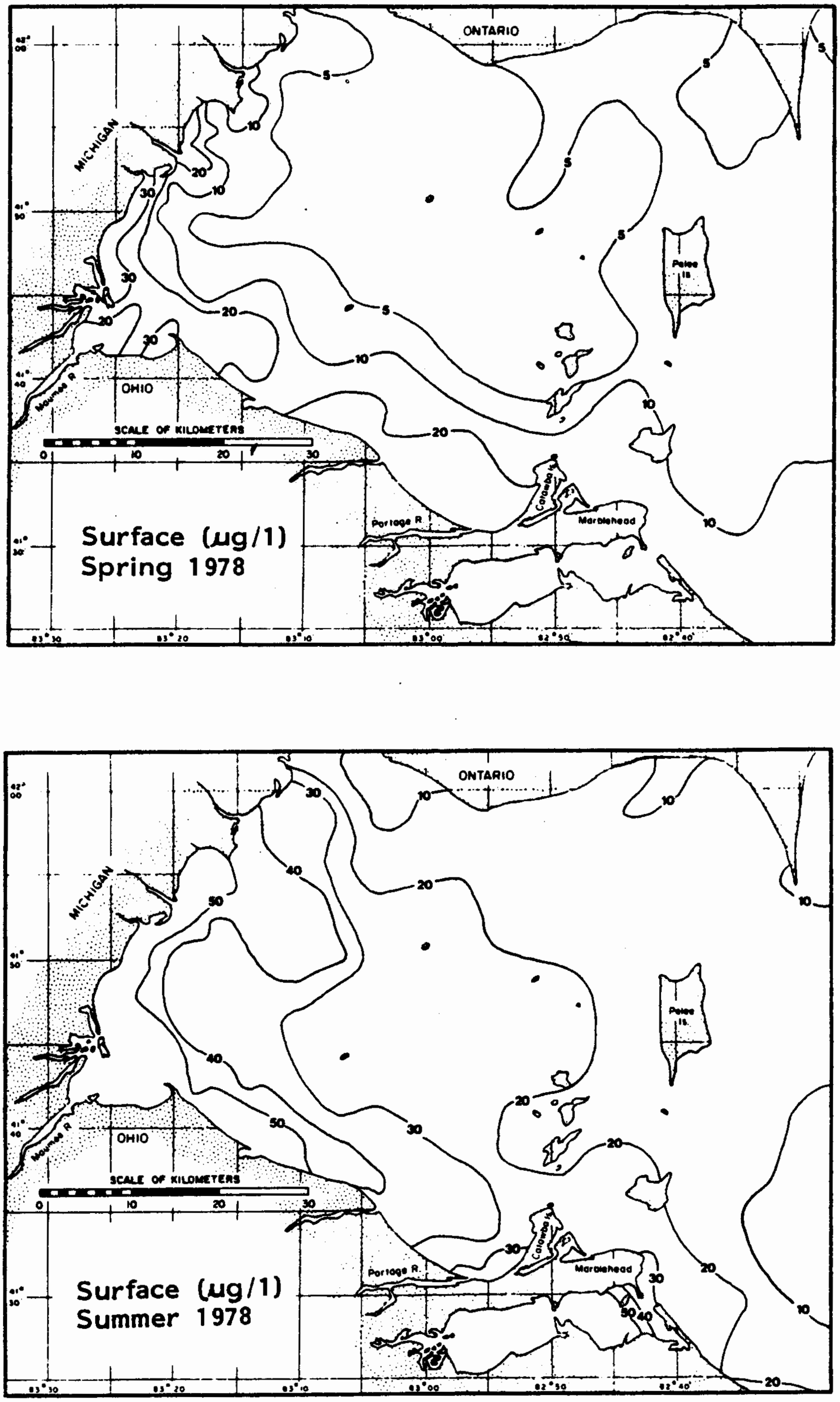


FIGURE 37. DISTRIBUTION OF CHLOROPHYLL a IN LAKE ERIE WESTERN BASIN

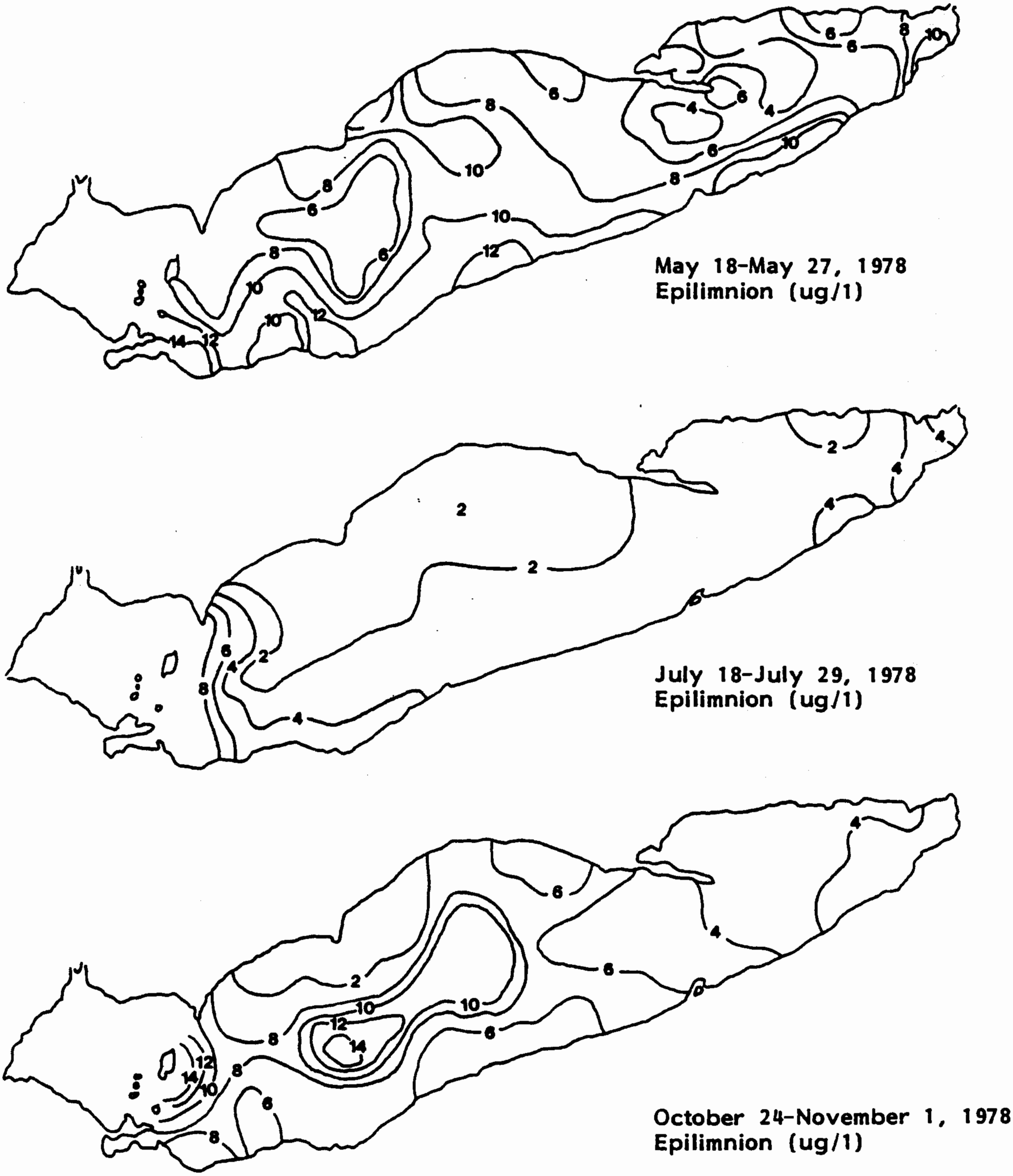


FIGURE 38. DISTRIBUTION OF CHLOROPHYLL a IN LAKE ERIE - CENTRAL AND EASTERN BASINS.

Nearshore concentrations of chlorophyll a (Figure 39) correspond to the same patterns observed for phosphorus (Figure 26). The most significant difference was for Maumee Bay (nearshore reach no. 11) were chlorophyll is high, but proportionally lower than phosphorus values. The high sediment turbidity of these waters is thought to be the major cause, resulting in reduced light levels for photosynthesis.

Volume-weighted cruise mean quantities of chlorophyll a for the period 1970 to 1982 are plotted on Figure 40. Although no convincing trend is apparent, the minimum and maximum annual cruise means for the latter half of the period are noticeably lower than those for the earlier years.

During each of the two years of the Intensive Study the western basin phytoplankton biomass was dominated by diatoms in the spring and co-dominated by diatoms and blue-greens through the summer and fall. This pattern is similar to that reported for 1970 by Munawar and Munawar (1976). In the central and eastern basins diatoms and greens represented the major contributors to the phytoplankton commmunity throughout the season. Diatom biomass was high in the early spring and in the fall following lake turnover. Green algae dominated in the summer but at a lower biomass than the diatom peaks. Studies of biomass distribution by USEPA/GLNPO indicate a west-to-east decrease in the standing crop of algae for the three basins:

Mean Phytoplankton Biomass of Lake Erie

Year	Western Basin (g/m^3)	Central Basin (g/m^3)	Eastern Basin (g/m^3)
1978	4.0	1.8	1.2
1979	9.4	3.4	0.9

The highest concentrations of phytoplankton were observed along the United States shore of all three basins.

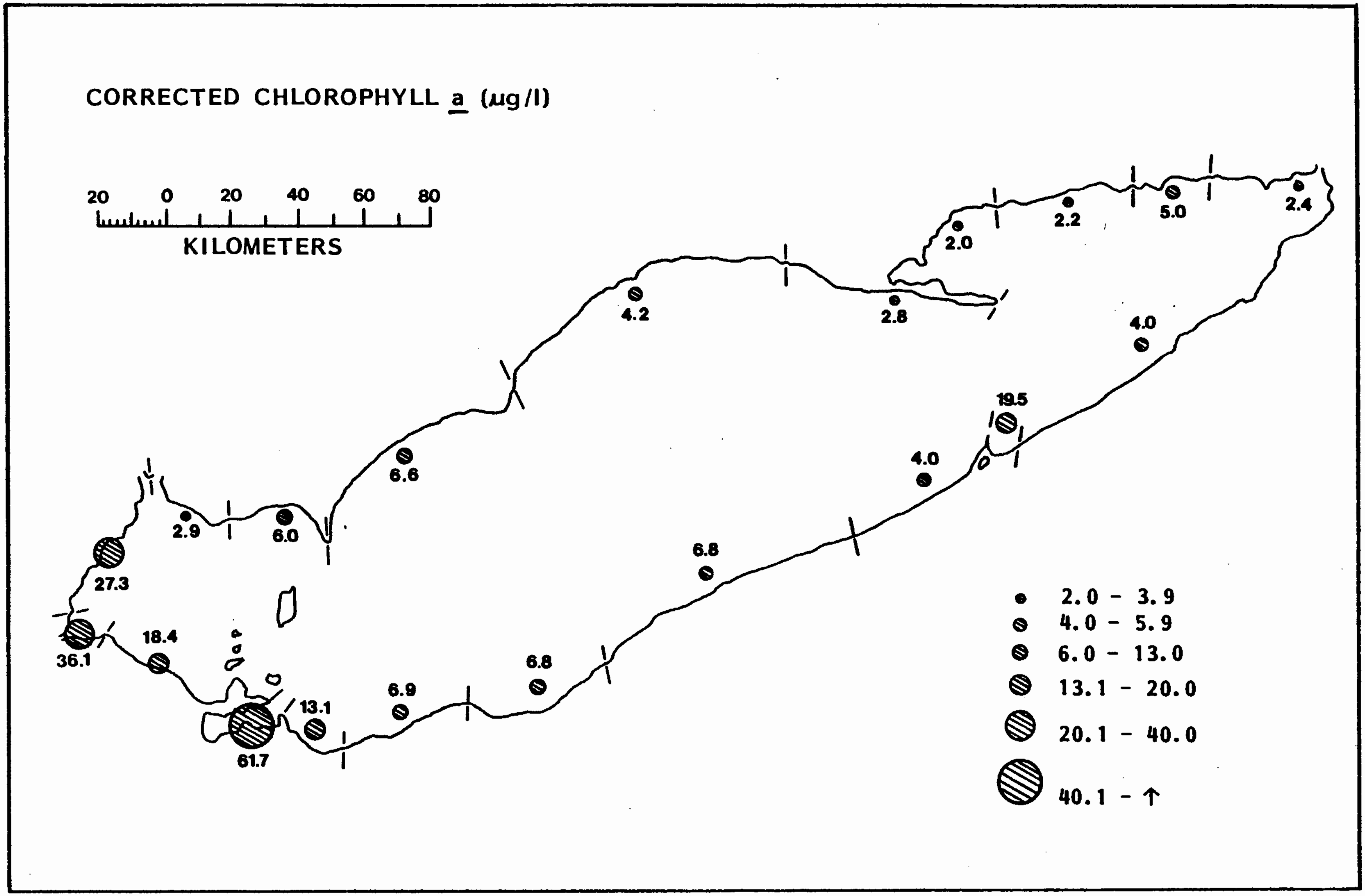


FIGURE 39. MEAN NEARSHORE CONCENTRATION OF CHLOROPHYLL a (1978-1979)

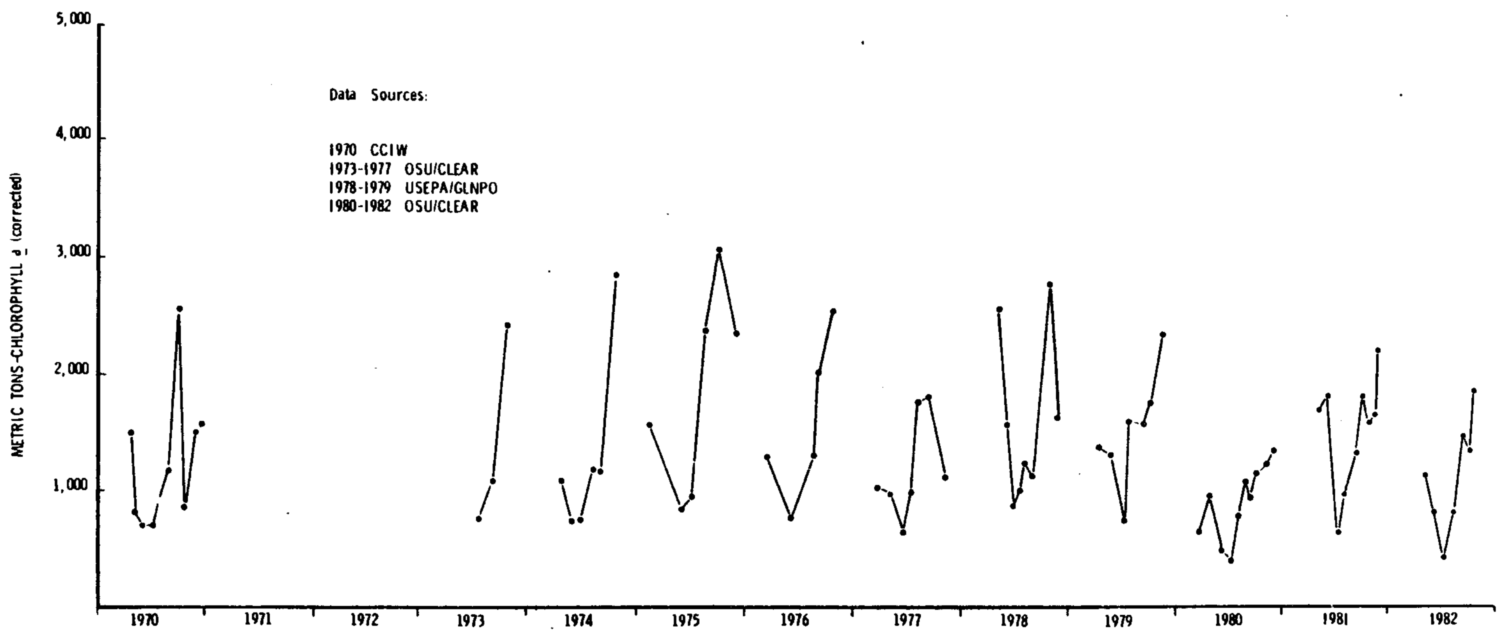


FIGURE 40. CHLOROPHYLL a QUANTITIES IN LAKE ERIE-CENTRAL BASIN

The basin-wide blooms of blue-greens in western Lake Erie which were so prevalent in the mid-1960s decreased in intensity and number in the 1970s. No basin-wide blooms were reported during the Intensive Study, although USEPA/GLNPO noted visible algal blooms in the western basin (up to 17 g/m^3) in August, September and October 1979 with associated whiting presumably due to $CaCO_3$ precipitation. Open lake phytoplankton analysis, from an index station in each of the three basins between 1970 and 1980, indicates a reduction in total phytoplankton biomass and a composition shift toward more oligotrophic species. Several eutrophic species were less abundant in 1979 than in 1970 and two oligotrophic species were first observed in 1979 (Munawar 1981). Analysis of samples from the Kingsville water intake along the northern shore of western Lake Erie indicates a marked decline in algal biomass in recent years. This apparent improvement along the Ontario shore has not been observed in the Michigan or Ohio nearshore water. This may be explained by the phosphorus decrease in the Detroit River outflow, which strongly influences the Ontario shore (Figure 24), versus high concentrations of phosphorus in the Maumee River and other tributaries which influence the United States shore.

The filamentous, epilithic green alga Cladophora glomerata is well-adapted to rocky littoral reaches of Lake Erie, as evidenced by its profuse growth. This alga has been reported in Lake Erie since the late 1800s, but in the past few decades it has become increasingly abundant. Massive growths of Cladophora have created nuisance accumulations and obnoxious odors along recreational shores. It may also clog water intakes, foul fishing nets and submerged structures, and impede navigation due to growths on boat hulls. Thomas (1975) suggests that the Cladophora starts to become a nuisance at phosphorus concentrations of 15 ug/l, and it is only above this level that it interferes with certain water uses, especially recreation and drinking water. Because of the high concentrations of phosphorus in the nearshore waters of all three basins (Figure 26), the distribution and abundance of Cladophora in Lake Erie is largely limited by the lack of suitable substrate. The most extensive growths of Cladophora are located in the eastern basin nearshore and the islands region of the western basin due to the large areas of exposed bedrock. The distribution of Cladophora was quantified in all three basins of the lake during the Intensive Study. Five sites were investigated including two in the western basin (Stony Point, Michigan -- Site 1 and South Bass Island, Ohio -- Site 2), one in the central basin (Walnut Creek, Pennsylvania

— Site 3) and two in the eastern basin (Hamburg, New York — Site 4 and Rathfon Point, Ontario — Site 5). The results of surveys conducted in 1979 and 1982 are summarized below:

Maximum Standing Crop of Cladophora in Lake Erie

Year	Western Basin		Central Basin	Eastern Basin	
	Site 1 (g/m^2)	Site 2 (g/m^2)	Site 3 (g/m^2)	Site 4 (g/m^2)	Site 5 (g/m^2)
1979	107	110	24	100	983*
1980	186	218	59	86	—
1981	116	200			
1982	110	88			

*results questionable

From the abundant growth observed along the Ontario shore of the eastern basin, it is suspected that light attenuation is relatively small here when compared with the more turbid waters of the western basin where light is a major limiting factor to Cladophora growth. Correspondingly, the depth of maximum growth was found to range from 0.5 meters for the western basin to 3.0 meter in the eastern basin. The lack of sufficient historical data preclude the establishment of biomss trends for this alga.

Nearshore and open lake trends. An analysis of Lake Erie water quality data for the past decade indicates that Lake Erie is no longer becoming more eutrophic each year as has been reported for earlier decades of this century (Beeton 1961 and 1965). As discussed earlier, several parameters show modest signs of improvement.

An analysis of the United States nearshore waters of the Detroit River indicates a decreasing trend in alkalinity, conductivity, turbidity, total dissolved solids (TDS), biochemical oxygen demand (BOD), ammonia, total Kjeldahl nitrogen, total organic carbon, total phosphorus, soluble phosphorus, phenols, iron, and chloride. No trends could be detected for silica, organic nitrogen, or total and fecal coliforms. With the exception of nitrate plus nitrite, no parameter at this reach is increasing significantly through time. Thus, a general improvement in the quality of water appears to be occurring along the western shore of the river.

The Livingstone Channel, which is considered representative of upper Great Lakes water, showed significant decreases in conductivity, ammonia, total Kjeldahl nitrogen, total organic carbon, total phosphorus, soluble phosphorus, phenols and chloride. No significant trends were found for temperature, turbidity, silica, BOD, organic nitrogen, nitrate plus nitrite or iron. Again, a general improvement in water quality is indicated for mid-river flow.

The Canadian shore of the Detroit River shows significant decreases in total organic carbon, total phosphorus, soluble phosphorus, total coliforms and phenols. No significant trends were observed for temperature, dissolved oxygen (DO), turbidity, TDS, silica, BOD, organic nitrogen, ammonia, total Kjeldahl nitrogen, nitrate plus nitrite, iron or chlorides. Increases through time were observed for pH, conductivity, and fecal coliforms. Thus, while not as many parameter trends are significant at this site than at the other two segments in the Detroit River, a general improvement in water quality can be ascertained by decreases in major nutrient concentrations, total coliforms, and phenols.

Monroe, Michigan water intake data show only an increasing trend in phenols; all other parameters of interest were either not present in the data set or showed no significant change. Although the data set is limited, the analyses of existing nutrient and major ion parameters indicates that water quality at this site in the lake may not have changed significantly within the period of record.

Data from samples collected at the mouth of the Maumee River (Toledo, Ohio) indicate significant decreases in nitrate and total phosphorus. These results may reflect a decreased nutrient load from the Maumee River watershed. The data also revealed decreasing trends in pH and alkalinity, suggesting that some acidification is occurring. DO is decreasing while BOD is increasing through time, indicating an increase in the amount of biologically oxidizable organic matter in the Maumee River estuary. DO levels in the lower Maumee River frequently violate IJC water quality objectives. No significant trends were evident for temperature, conductivity, turbidity, TDS, or ammonia.

Because of the estuarine conditions at the mouth of the Maumee River, samples taken there may be poor indicators of Maumee River nutrient and sediment loads. It is noteworthy that the Maumee River carries about 38% as much nitrate as the Detroit River although its average discharge at 2200 m^2/sec is only 3% of the Detroit River flow. Historical records for nitrate concentrations in the Maumee River also show a significant increase.

Data collected from the Cleveland, Ohio Crown water intake from 1974 to 1980 indicated significant increases in temperature, alkalinity, total organic carbon, and fecal coliforms, as well as significant decreases in pH and turbidity. No signficiant trend was evident in DO, conductivity, nitrates, ammonia, total phosphorus, or chloride. Thus the water quality at this location does not appear to be changed greatly over the period of record.

Erie, Pennsylvania water intake data show a significant decrease in pH, alkalinity, total and fecal coliforms, iron, and chloride values. No significant trends were evident for temperature or total phosphorus values. The only parameters which indicated an increase through time were DO and turbidity.

Data from the Black Rock Canal at Buffalo, New York (discharge of the Buffalo River) indicated a significant increase in pH and a significant decrease in chlorides. No other changes were evident indicating no detectable changes in water quality parameters over the period of record (1969-1980). Decreasing trends in pH, organic nitrogen and chlorides were found for the Niagara River downstream from the Black Rock Canal. Soluble phosphorus was the only parameter for which an increasing trend was discerned. No significant trend could be found for temperature, alkalinity, conductivity, turbidity, BOD, nitrates, ammonia, total coliforms, phenols, or iron. The Niagara River at Lake Ontario showed no significant increase or decrease in pH, alkalinity, DO, turbidity, organic nitrogen, nitrate, ammonia, total coliforms, or iron. The only significant trends which could be discerned were an increase in temperature and decreases in conductivity and chloride. Thus, in respect to these components, the Niagara River system does not appear to have changed significantly during the last decade.

Two recent statistical studies have been completed to determine the existence of open lake water quality trends in Lake Erie. Kasprzyk (1983) analyzed total phosphorus and chlorophyll a data for the period 1974 to 1980 and El-Shaarawi (1983b) looked at these parameters plus several others for the period 1968 to 1980. In both studies the western, central and eastern basins were analyzed separately. Kasprzyk only used data from the non-stratified period (spring and fall) whereas El-Shaarawi used the approach of adjusting the entire annual data set for seasonal variatons. The essential results of these studies are summarized below:

Trends in Total Phosphorus

Investigator	Basin	Data Set	Trend
Kasprzyk			
	Western	1974-80	Insufficient data
	Central (west)	1974-80	Spring - decreasing; Fall - none
	Central (east)	1974-79	None
	Eastern	1974-79	None
El-Shaarawi			
	Western	1968, 70-72, 77, 78	Increasing 1968-71; Decreasing 72-78
	Central	1968, 70-72, 77-80	Decreasing 1968-80
	Eastern	1968, 70-72, 77, 78, 80	Decreasing 1968-80

Trends in Chlorophyll a

Investigator	Basin	Data Set	Trend
Kasprzyk			
	Western	1974-80	None
	Central (west)	1974-80	Spring - none; Fall - decreasing
	Central (east)	1974-80	Spring - none; Fall - decreasing
	Eastern	1974-79	Spring - none; Fall - decreasing
El-Shaarawi			
	Western	1968, 70, 72	Increasing 1968-72*
	Central	1968, 70, 79, 80	Decreasing 1970-80
	Eastern	1968, 70, 72, 80	Decreasing 1968-80

*Non-significant, increasing trend

These advanced statistical studies have yielded some significant, but not dramatic, water quality trends for the past decade. These trends are in general agreement with those found by the Technical Assessment Team as discussed earlier in this report (Figures 21-23 and 34-36).

Long-term trends in the rate at which oxygen is depleted in the summer hypolimnion of Lake Erie has been a recent topic of debate within the scientific community. Carr (1962) suggested that oxygen consumption was increasing in the central basin. Dobson and Gilbertson (1972) agreed with this general conclusion and calculated a trend of 0.079 mg/l/day for the period 1930-1970. Charlton (1979), on the other hand, after standardizing the depletion rate to account for physical factors such as temperature and hypolimnion thickness, concluded that there was no significant trend in the dissolved oxygen consumption rate. Burns and Rosa (1981) supported the hypothesis of an increasing long-term trend by accounting for other physical parameters, including temperature, vertical mixing, and incoming oxygen resulting from the entrainment of eastern basin water. The most resent study is a statistical model developed for dissolved oxygen concentrations in the hypolimnion of the central basin using data collected by CCIW during the period 1967-1979 (El-Shaarawi 1983a). Using water level, hypolimnion temperature and total phosphorus as explanatory variables, it was found that depletion rate is completely independent of temperature and depends only on water level and total phosphorus. However, the initial dissolved oxygen concentration in the hypolimnion was found to be a function of temperature, total phosphorus and water level. When the model was used to show the historical trend in the oxygen depletion rate, after the removal of the effect of temperature and water level, it was concluded that the increase in depletion is related to the increase in the level of total phosphorus. Further, when the model was used to estimate the probability of anoxia in the central basin as a function of the three explanatory variables, it was concluded that there is "always" a high chance for the occurrence of anoxia and this chance increases with the increase in the level of total phosphorus. The final conclusion of the study was that "it is possible to improve the anoxic conditions in the lake by controlling total phosphorus loading." The conclusions of El-Shaarawi (1983a) are consistent with those of the Technical Assessment Team as discussed in the Dissolved Oxygen and Nutrients sections of this report.

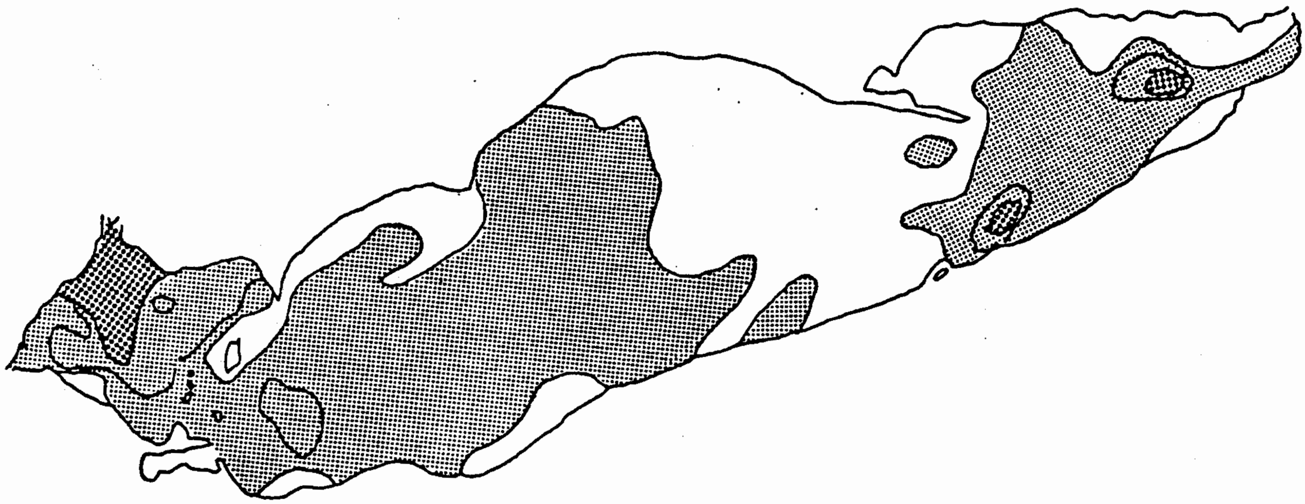
Toxic Substances

Toxic pollutants are introduced to Lake Erie through municipal and industrial point source wastewater discharges, atmospheric deposition, and urban and agricultural land runoff. In Lake Erie, interlake transfer via the connected channels (Detroit and Niagara rivers) can also be a significant source of contaminants. Preliminary data indicate that nine heavy meals (Cd, Cr, Cu, Pb, Mn, Hg, Ni, Ag and Zn) and six organic pollutants (benzene, chloroform, methylene chloride, bis [2 ethylexyl] phthalate, tetrachloroethylene, and toluene) were found in nearly all effluents from major municipal wastewater treatment plants in the Lake Erie basin. The International Joint Commission (1979) has compiled an inventory of the major municipal and industrial point source discharges to Lake Erie. The total annual load to Lake Erie from these sources for four trace metals is summarized below:

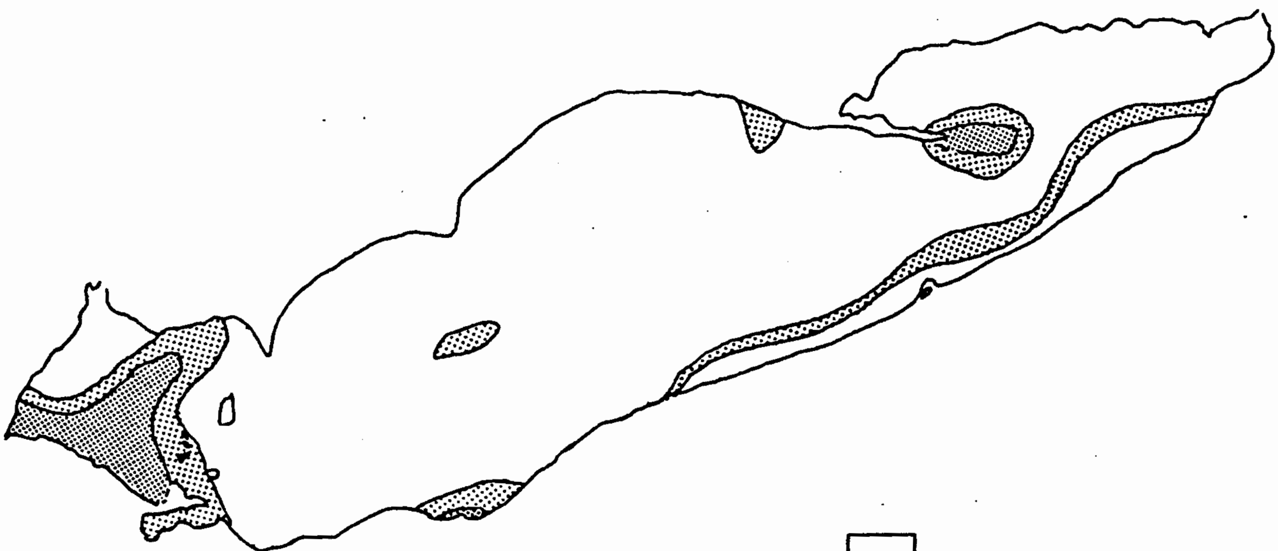
Annual Trace Metals Loading to Lake Erie

Metal	Municipal Sources (metric tons)	Industrial Sources (metric tons)
Zn	228.2	148.6
Pb	50.7	38.2
Cu	50.7	43.4
Cd	15.2	0.3

Data from the 1979 main lake surface sediment survey indicate that some metals are highly concentrated offshore from tributary mouths near major industrial areas. Lead, nickel, copper, silver, vanadium, mercury (Figure 41), zinc, cadmium, and



MERCURY IN SURFACE SEDIMENT 1970
(THOMAS AND JAQUET 1976)



MERCURY IN SURFACE SEDIMENTS 1979
(USEPA/GLNPO)

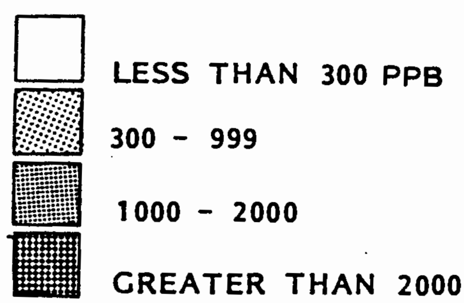


FIGURE 41. COMPARISON OF MERCURY CONCENTRATION IN LAKE ERIE SEDIMENTS FOR 1970 AND 1979.

chromium show elevated levels offshore from the Detroit River. Mercury (Figure 41) is also high along the Pennsylvania/New York shoreline. Zinc and cadmium show high concentrations off Cleveland, Ohio and Erie, Pennsylvania. Chromium is also high near Buffalo, New York. The distribution of metal in the open lake sediments indicated highest mean concentrations corresponding to the major depositional zones particularly evident in the sink areas of the central and eastern basins. It is evident that the western basin sediments are eventually transported into the adjoining basins with the net movement from west to east.

Drynan (1982) points out that combined sewer overflows are an additional point source of toxic substances for which little or no information is currently available. It is very difficult to sample and obtain flow measurements for these highly variable discharges in order to make estimates of the total quantities of pollutants they introduce into the lakes. In some of the major metropolitan areas, such as Detroit and Cleveland, with combined sewers these discharges may be significant, particularly in terms of local water quality impacts. However, neither these contributions to total pollutant loadings nor impacts to whole lake water quality have been quantified.

With further controls on point source discharges, it is becoming increasingly apparent that diffuse sources, urban and agricultural land drainage, and long range atmospheric transport and deposition must be given more consideration in water quality management plans. Although the quantification of atmospheric deposition of trace metals and organic substances to Lake Erie is hampered by a number of problems, Drynan (1982) concluded that it is possible to use approximations of wet and dry components to estimate total deposition. His estimates for selected airborne substances are summarized below:

Annual Deposition of Airborne Substances in Lake Erie

Trace Metal	Metric Tons	Organic Compound	Metric Tons	Organic Compound	Metric Tons
		Total PCB	3.1	Anthracene	1.5
Pb	754	Total DDT	0.19	Phenanthrene	1.5
Cu	151	α-BHC	1.1	Pyrene	2.6
Cd	75	γ-BHC	5.0	Benz(a) athracene	1.3
Ni	75	Dieldrin	0.17	Perylene	1.5
Fe	3,270	HCB	0.53	Benzo(a) pyrene	2.5
Al	*	p,p' Methoxychlor	2.6	DBP	5.0
Mn	*	α-Endosulfan	2.5	DEHP	5.0
Zn	*	β-Endosulfan	2.5	Total organic carbon	66,000
		Total PAH	51.0		

*Estimates not possible from available data

Shipboard collection of aerosol samples was undertaken as part of the Lake Erie Intensive Study to assess the contribution of atmospheric dry loading of aerosol trace elements and nutrients to the lake (Sievering 1982). Preliminary estimates of loading to Lake Erie are summarized below:

Annual Atmospheric Dry Loading to Lake Erie

Element	Metric Tons	Element	Metric Tons
Pb	4-9	Cr	5-12
Zn	75-175	Ni	4-8
Cd	4-9	SO_4	30,000-70,000
Cu	3-7		

The range in values shown are considered to be the 25% and 75% confidence limits of these estimates.

Sediment cores taken at the mouth of the Detroit River and in western Lake Erie in 1971 yielded surface mercury values up to 3.8 ppm and generally decreased in concentration exponentially with depth (Figure 41). High surface values were attributed to waste discharge from chlor-alkali plants on the Detroit and St. Clair rivers which operated during the period 1950 to 1970. Several years after these plants diminished operation the area was again cored with analyses showing that recent deposits covered the highly contaminated sediment with a thin layer of new material which had mercury concentrations approaching background levels (0.1 ppm). As a result of these discharges, mercury in fish of Lake St. Clair and western Lake Erie was a major contaminant problem in the early 1970s. Levels of total mercury in walleye (Stizostedion vitreum vitreum) collected from Lake St. Clair have declined from over 2 ug/g in 1970 to 0.5 ug/g in 1980. In western Lake Erie, 1968 levels of mercury were 0.84 ug/g as compared to only 0.31 ug/g in 1976. The rapid environmental response subsequent to the cessation of the point source discharges at Sarnia, Ontario and Wyandott, Michigan can be attributed to rapid flushing of the St. Clair-Detroit River system, the high load of suspended sediment delivered to western Lake Erie, and the high rate of productivity in the western basin (International Joint Commission 1981).

Fish contaminant surveys of Lake Erie and its tributaries in the late 1970s indicate few contamination problems, and these are usually associated with site specific areas. The highest concentration and the greatest number of organochlorine contaminants in fish samples were found in the River Raisin and the Maumee River. Excessive concentrations (i.e. 1.0 ppm for pesticides, 5.0 ppm for total PCBs) of the following contaminants were found: -BHC (Ashtabula River) and total PCBs (River Raisin, Maumee River, and Sandusky River). All other contaminants were at low concentrations (less than 1.0 ppm). Levels of PCB and DDT in spottail shiners (Notropis hudsonius) and in herring gull (Larus argentatus) eggs have declined in the past decade, illustrating a system-wide response to controls on production and use of these compounds. PCB levels in shiners at Point Pelee, Ontario, dropped from 844 ng/g in 1975 to 150 ng/g in 1980 while during the same period DDT fell from 92 to 21 ng/g. At Port Colborne, Ontario, gull eggs showed similar declines in PCB and DDT residues, but of a lesser magnitude (International Joint Commission 1981).

Public Health

Bacteria contaminated wastewater inputs to the lake pose a direct health hazard near metropolitan centers such as Port Clinton, Lorain, Cleveland, Dunkirk, Buffalo, Port Stanley, and Port Burwell. As seen below, studies by USEPA/GLNPO show approximately 16% of all beaches along the Lake Erie shore were either permanently or temporarily restricted from use, particularly for water contact recreational activities, during the period 1978-1981:

Lake Erie Recreational Beaches

Jurisdiction	Beaches Monitored	Beaches Temporarily Closed or Restricted	Beaches Permanently Closed
Michigan	7	0	0
Ohio	52	8	4
Pennsylvania	40	1	0
New York	26	5	0
Ontario	4	2	0

In the past decade, significant progress has been made in removing bacterial contamination from the shoreline. In the late 1960s, 11 bathing beaches on the United States side of the lake were posted unsafe because of high bacterial contamination. Another 12 beaches were deemed as questionable because of moderate bacterial pollution and 27 were considered generally safe with only slight pollution. Only three beaches were found to be uncontaminated throughout the swimming season (FWPCA 1968b). By contrast, the above data show that over 100 beaches are now safe. For example, in the late 1970s the beach at Sterling State Park (near Monroe, Michigan), after a 20-year closure, was reopened when coliform bacteria levels reached compliance for body contact recreation. The major bacterial problems that still persist are often associated with storm water overflows, such as at Cleveland, Ohio where heavy flows are delivered directly to the Cuyahoga River, contaminating the nearshore waters surrounding the metropolitan area.

Land Use Activities

The United States portion of the Lake Erie basin includes 12.5 million acres (5.1 million hectares), of which over half is cropland. In the western portion of the basin, nearly 70 percent of the land is cropland. The soils of this area are favorable for row crop production with corn and soybeans dominating cropland usage. The U.S. Army Corps of Engineer's Lake Erie Wastewater Management Study (Yaksich 1982) showed that the effect of land use activities on water quality is a complex relationship, although the following generalizations were confirmed and recommendations proposed:

1. The rivers which drain into western and central Lake Erie are hydrologically active throughout their entire watersheds and contribute diffuse loads of phosphorus to the lake.

2. The mean ratio of total phosphorus to suspended solids in northwestern Ohio streams was 2.17 g/kg. Of this total, 25% was soluble phosphorus, which was readily available for algal growth, and 75% was particulate phosphorus, which is partially available. In general, higher concentrations of suspended solids resulted in lower phosphorus to suspended solids ratios.

3. Particulate and soluble phosphorus entering stream systems disappears rapidly from flowing water; however, it is resuspended and transported downstream as particulate phosphorus during later storm events. Therefore, the process of transporting phosphorus from basin cropland to Lake Erie may require a considerable period of time.

4. The western basin and southwestern portion of the central basin of Lake Erie have algal growth problems which will require phosphorus reductions in addition to those being provided (or projected) by point source removal. A program for control of phosphorus from diffuse sources is therefore recommended which has the lowest cost per unit quantity of phosphorus stopped from reaching the lake. Conservation tillage on suitable soils is the most cost-effective means of reducing sediment phosphorus loads to Lake Erie.

5. The implementation of a conservation tillage program could ultimately achieve a 2,000 mt/yr reduction in total phosphorus loading to Lake Erie. The Great Lakes Water Quality Agreement of 1978 calls for an additional target phosphorus reduction for Lake Erie of 2,000 metric tons per year beyond the achievement of a 1.0 mg/l effluent concentration for all municipal wastewater treatment plants currently discharging more than 1 million gallons per day. The United States portion of this reduction should be 1,700 mt/yr. A conservation tillage program will more than reach this goal at a benefit/cost ratio of 10:1.

6. A new base-year tributary phosphorus load to Lake Erie should be recognized; inclusion of tributary monitoring data from 1978-1980 in the computation gives a base-year total phosphorus load of 16,455 mt/yr. When the 1.0 mg/l effluent limitation has been achieved the total phosphorus load to Lake Erie will be 15,025 mt/yr. At that time an additional phosphorus reduction of 4,025 mt/yr (not 2,000 mt/yr as stated above) will be required to meet the 11,000 metric tons per year total loading objective of the Water Quality Agreement. The United States allocation of this reduction objective should be approximately 2,800 mt/yr. To reach this reduction objective, an additional 770 mt/yr in reductions beyond the Agreement program must be achieved through point source controls beyond the 1.0 mg/l effluent limitation. This would cost an estimated $5 million annually. The benefit/cost ratio of a conservation tillage program is 17:1 compared to a program requiring the entire reduction to be achieved by point source control.

7. Relatively small amounts of agricultural pesticides reach water bodies via runoff (normally less than 2% of the application or as high as 6% after intense rainfall). Pesticides generally used in the Lake Erie basin are not inhibitory to invertebrates or fish at runoff concentrations; however, algae and aquatic macrophytes may be inhibited at stream concentrations. The increased usage of pesticides with conservation tillage is not expected to result in increased pesticide runoff since erosion and runoff would be decreased.

Lake Responses to Remedial Actions

The water from Lake Erie sustains the vast industrial complex which extends from Detroit to Buffalo. Water returned to the lake is highly enriched by municipal, agricultural, and industrial waste products. Studies conducted in the late 1920s revealed that the lake was already moderately rich in nutrients and was experiencing phytoplankton blooms in its western basin. Adjacent to the Detroit River mouth, pollution-sensitive mayflies were being replaced by tubificid worms. By the mid-1950s thermal stratification was resulting in oxygen depletion in the bottom water and mayfly nymphs suffered catastrophic mortality. The concentration of all the major ions, including nutrients such as phosphorus and nitrogen, showed a marked increase during this period of time.

In the early 1960s Lake Erie gained the reputation as a "dead lake" with its western basin the consistency of "pea soup" due to dense algal mats which left green wakes behind motorboats. Most municipal beaches were closed owing to high coliform bacteria counts or were rendered unusable by reeking masses of decaying algae (largely Cladophora glomerata). One of its major tributaries, the Cuyahoga River, was so polluted by industrial wastes that it periodically caught fire. Anoxia in the central basin had caused the extirpation of virtually all cold-water fish species, and detergent foam at the eastern end of the lake resulted in a disgusting spectacle in the plunge pool of Niagara Falls.

The concept of nutrient control for Lake Erie appears to have had its origin in 1965, when the U.S. Department of Health, Education and Welfare convened a conference on the pollution of Lake Erie and its tributaries under the authority granted in the Water Pollution Control Act of 1961. One of the recommendations forthcoming from the conference was that a "technical committee" be established to evaluate water quality problems related to nutrients in Lake Erie and to make recommendations to the conferees. In late 1965, the Lake Erie Enforcement Technical Committee was formally established to explore the problems related to nutrients and over-enrichment of Lake Erie. The committee received information and advice from leading authorities in water-oriented disciplines. After a year of study, a final report was issued which concluded that the major pollution problems in Lake Erie result directly or indirectly from excess algae and that these growths are stimulated by nutrients resulting from human activities.

The technical committee recommended that water quality objectives be established that would prevent nuisance algae conditions, particularly by lowering the phosphate and nitrogen levels in the lake. The committee further recommended that new treatment processes be developed and employed to effect high phosphate removal. Based on these recommendations the Federal Water Pollution Control Administration (FWPCA), later the Federal Water Quality Administration (FWQA), and more recently the Environmental Protection Agency (EPA), as well as state and local agencies, have embarked on a program to control the flow of nutrients and toxic substances to Lake Erie. The necessity for this control was reinforced by findings of the International Joint Commission, resulting in the Canada-United States Water Quality Agreements of 1972 and 1978.

Nature of remedial actions. Today Lake Erie is beginning to respond to massive clean-up efforts started two decades ago. New sewage treatment plants have been constructed throughout the drainage basin and old plants have been modified to remove phosphates through tertiary treatment. Industries have been forced to reduce waste loads to the lake or in some instances cease operation, as in the case of chlor-alkali plants which discharged excessive amounts of waste mercury. Production and use of several toxic organic compounds have been banned. Agricultural practices are being modified to lessen soil loss to tributaries and to reduce fertilizer and pesticide requirements. The more significant actions include the following:

1. Detergent Modifications

   During the late 1960s and early 1970s, the province of Ontario and all of the Great Lakes states, with the exception of Ohio and Pennsylvania, enacted legislation limiting the amount of phosphorus permitted in household detergents. A concentration of 0.5% phosphorus is permitted in the United States and 2.2% in Canada. In Ohio, where no controls are in effect, phosphorus concentrations of 5.5% are typical.

2. Point source controls

   The most significant improvement in lowering phosphorus delivery to Lake Erie has been made in the loading from point sources. The point source loading has decreased from 11,900 mt/yr in 1970 to 4,500 mt/yr in 1980, as a result of the implementation of phosphorus effluent limitations to 1.0 mg/l at wastewater treatment plants (Yaksich 1982). In 1971, total phosphorus loading from the Detroit River accounted for 67% of the total load to the lake; by 1980, improvements in treatment had lowered this to 37% (Table 15).

3. <u>Soil conservation</u>
   The practice of conservation tillage has expanded rapidly in the Lake Erie basin throughout the last decade. In the early 1970s little conservation tillage was in use, but by 1981, reduced tillage was being practiced on 22% of the basin's cropland, and no tillage was used on 4%. Besides changing tillage, several other agricultural practices (e.g. method of fertilizer application, pesticide usage, planting techniques, and establishing green-belts along streams) have been altered, resulting in less soil loss and some reduction of phosphorus deliver to the lake.

4. <u>Fishery management</u>
   Several fish species have been extirpated from Lake Erie as a result of environmental changes, over-exploitation, or a combination of these factors. Prudent management programs, such as the suspension of commercial fishing for selected species, have enhanced the population of sport fish. Commercial and recreational harvests, environmental changes and management programs will continue to affect the fish community as a whole. To a large extent, the structure of Lake Erie's fish community in the future will depend to a large degree on public perception of what structure would be most economically advantageous.

<u>Positive responses</u>. Annual monitoring programs initiated in the early 1970s, coupled with observations during the 1978-1979 Intensive Study, are beginning to provide some evidence of water quality improvement and possible lake recovery. The first signs of a positive response to remedial programs have not been dramatic, but considering that the pollution of the lake also took place over many decades, a rapid recovery should not be expected. Some of the most promising indicators of improved lake conditions are presented below. Cause and effect relationships for all of these

changes are not well understood nor can these changes be attributed to specific remedial actions:

1. Lake Levels

Water levels in Lake Erie during the past decade have averaged 0.5 m above the 1960-1970 levels. The difference between the lowest year (1964) and the highest year (1973) was 1.1 m, an increase of approximately 7% in volume. The dilution effect of more upper Great Lakes water flowing into Lake Erie, coupled with greater submergence of algal attachment sites, is thought to be partially responsible for the absence of basin-wide algal blooms and massive growths of the filamentous algae, Cladophora, that were so prevalent in the mid-1960s.

2. Dissolved Substances

Nearshore records for the period 1900 to 1960 in central Lake Erie show dramatic increases in conductivity, chloride, calcium, sulfate, and sodium plus potassium (Beeton 1961 and 1965). From 1966 to 1980 conductivity (Figure 20) values indicate a decline in the total amount of dissolved substances in central Lake Erie, falling approximately 8% during this period. Chloride (Figure 20) shows a more dramatic improvement, dropping about 26% from a concentration of 25.0 mg/l in 1966 to 18.4 mg/l in 1979. Much of this decline can be attributed to elimination of waste brine pollution from the Grand River near Painesville, Ohio in the early 1970s. In the eastern basin, Presque Isle Bay at Erie, Pennsylvania, has experienced a marked decrease in alkalinity (largely bicarbonate ions) falling from 96 ppm in 1945 to 87 ppm in 1978. Other conservative ions (i.e. calcium, sodium, and sulfate) have ceased to increase in the lake and have remained relatively stable over the past decade.

3. Phosphorus Loading

Loading of total phosphorus to Lake Erie declined markedly during the past decade. The 1971 loading to the entire lake, from all sources except shore erosion, was approximately 18,800 metric tons. By 1980, the total phosphorus load had decreased to an estimated 13,500 metric tons. The

Detroit River, which supplies about 90% of the inflowing water to Lake Erie, has shown a remarkable improvement; phosphorus loadings decreased 60% during the same period, primarily as a result of improvements to the Detroit wastewater treatment plant.

In the early 1970s, the concentration of phosphorus in influent wastewater to municipal treatment plants averaged about 10 mg/l within the Lake Erie drainage basin and the mean effluent concentration was approximately 7 mg/l. By 1980, many plants had installed phosphorus removal systems which resulted in an average effluent concentration of 1.6 mg/l for all Ohio plants and concentrations as low as 0.6 mg/l for the Detroit sewage treatment plant in 1982 (Drynan 1982).

4. Phosphorus Concentrations

Concentrations of total phosphorus in western Lake Erie have not declined as noticeably as loadings, but some improvement has been documented for the north shore of the western basin (Figure 31). Elsewhere in the lake concentration have been relatively stable since 1970. If the monitored phosphorus concentration decreases are representative of the total load coming from that source, the lake water quality should eventually improve with diminished concentrations of phosphorus and chlorophyll.

5. Hypolimnion Oxygen

In the central basin of Lake Erie, the rate of hypolimnetic oxygen depletion more than doubled between 1930 and the mid-1970's. In 1930, the volumetric rate has been estimated at 0.054 mg/l/day (Dobson and Gilbertson 1971), while in 1974 it was measured at 0.130 mg/l/day. During the same period the area of the basin subjected to anoxic conditions rose from 300 km^2 in 1930 to 10,250 km^2 in 1974. Cruises conducted from 1980 to 1982 show that the demand rate has dropped to an average of 0.101 mg/l/day and the area of anoxia has been reduced to 4,870 km^2.

6. Toxic Metals and Organic Compounds

Sediment cores taken at the mouth of the Detroit River and in western Lake Erie in 1971 yielded surface mercury concentrations up to 3.8 ppm (Walter et al. 1974) and generally decreased exponentially with depth to background concentrations of less than 0.1 ppm. High surface values were attributed to waste discharge during the period 1950 to 1970 from chlor-alkali plants on the Detroit and St. Clair rivers. In 1977, several years after these plants diminished operation the area was again cored. Analyses showed that recent deposits were covering the highly contaminated sediment with a thin layer of new material which had mercury concentrations approaching background levels (Wilson and Walters 1978).

Mercury in fish of Lake St. Clair and western Lake Erie was a major contaminant problem in the early 1970s. Levels of total mercury in walleye (Stizostedion vitreum vitreum) collected from Lake St. Clair have declined from over 2 ug/g in 1970 to 0.5 ug/g in 1980. In western Lake Erie, 1968 levels of mercury were 0.84 ug/g as compared to only 0.31 ug/g in 1976 (International Joint Commission 1981). The rapid environmental response subsequent to the cessation of the point source discharges at Sarnia, Ontario and Wyandott, Michigan can be attributed to rapid flushing of the St. Clair-Detroit River system and the high load of suspended sediment delivered to western Lake Erie.

Levels of PCB and DDT in spottail shiners (Notropis hudsonius) and in herring gull (Larus argentatus) eggs have declined in the past decade, illustrating a system-wide response to controls on production and use of these compounds. PCB levels in shiners at Point Pelee dropped from 844 ng/g in 1975 to 150 ng/g in 1980 while during the same period DDT fell from 92 to 21 ng/g (International Joint Commission 1981). At Port Colborne, gull eggs showed similar declines in PCB and DDT residues, but lesser in magnitude.

7. Algal Density and Composition

The basin-wide blooms of planktonic blue-green algae (Microcystis, Aphanizomenon and Anabaena) in western Lake Erie and massive growths of an attached, filamentous green algae (Cladophora glomerata) which were so prevalent in the mid-1960s, have decreased in intensity and number in the 1970s. No basin-wide blooms have been reported in recent years. Open lake phytoplankton analysis between 1970 and 1980 indicates a reduction in total phytoplankton biomass and a composition shift toward more oligotrophic species. Eutrophic species (i.e. Melosira granulata, Stephanodiscus tenius and S. niagara) were less abundant in 1979 than in 1970, and oligotrophic species (i.e. Dinobryon divergens and Ochromonas scintillans) were first observed in 1979 (International Joint Commission 1981; Munawar 1981).

8. Benthic Communities

The composition of the benthic macroinvertebrate communities of western Lake Erie has improved since 1967. Samples taken in 1979, when compared with 1967 data, showed that the bottom is still dominated by pollution tolerant tubificids (i.e. Limnodrilus hoffmeisteri, L. cervix and L. maumeensis); however, other less tolerant taxa of tubificids (i.e. Peloscolex spp.) were also common. The density of tubific worms declined sharply at the mouth of the Detroit River between 1967 (13,000/m^2) and 1979 (2,400/m^2), while the number at the mouth of the Maumee River has remained constant. Midge (Chironomidae) larvae represented only 6% of the western basin benthic population in 1967 but rose to 20% by 1979 (Ontario Ministry of the Environment 1981), replacing some of the tubificids.

A modest reestablishment of the burrowing mayfly (Hexagenia limbata) has been observed at the mouth of the Detroit River and adjacent areas of western Lake Erie. This species was extirpated from the western basin in the mid-1950s following periods of anoxia in this normally unstratified portion of the lake. Prior to 1953, bottom sediments yielded about 400 nymphs per square meter in the Bass Islands region (Britt 1956 and 1973). Following the catastrophic kills of the 1950s, no Hexagenia nymphs were found in Lake Erie sediments for over 20 years. In 1979, 20 nymphs were collected near the mouth of the Detroit River (Ontario Ministry of the Environment 1981) and for the past several years a small emergence of adults has been observed on South Bass Island.

9. Fishery

The annual sport angler harvest of fish in the Ohio waters of Lake Erie has increased from 5.2 million kg in 1975 to 7.3 million kg in 1982, an increase of 40% (Ohio Division of Wildlife 1983). During this eight-year period, yellow perch (Perca flavescens) harvests rose from 3.7 million kg to 5.5 million kg, while walleye (Stizostedion vitreum vitreum) production jumped from 0.5 million kg to 1.4 million kg. The increased walleye production has been attributed to good young-of-the-year recruitment and international management approaches to control sport and commercial harvests. The abundance of walleye within western Lake Erie also increased dramatically from 1970 to 1982. During the 1960s and early 1970s the "fishable" population of walleye, 14.5 inches (36.8 cm) in length and larger, was estimated at or below two million individuals. In 1982, the fishable population in western Lake Erie was estimated at over 25 million walleye (Ohio Division of Wildlife 1983).

10. Bathing Beaches

In 1967, 11 Lake Erie bathing beaches on the United States side of the lake were posted unsafe because of high bacterial contamination (FWPCA 1968b). Another 12 beaches were deemed as questionable because of moderate bacterial pollution and 27 were considered generally safe with only slight pollution. In 1967, only 3 beaches were found to be uncontaminated throughout the swimming season. By contrast, in 1981, only 4 beaches were closed throughout the year, 8 were open for restricted use and 76 were open as safe, uncontaminated beaches.

Continuing and emerging problems. The only major open water quality objective for which compliance has not been met is dissolved oxygen of the hypolimnion in central Lake Erie. The Water Quality Agreement calls for year-round aerobic conditions. The attempt to control anoxia in Lake Erie has been through the implementation of secondary and tertiary treatment at United States municipal sewage plants, phosphorus removal to 1.0 mg/l at sewage treatment plants larger than 1 mgd in the Lake Erie basin, limitations on phosphorus in detergents, and control of diffuse source inputs. The target load for these phosphorus controls is 11,000 mt/yr as determined by the mathematical models of DiToro and Connolly (1980).

The 1978 Water Quality Agreement requires the development of new phosphorus target loads and the allocation of these loads between Canada and the United States. As part of this negotiation process, base phosphorus loadings ("base loads") were developed for the lower Great Lakes. The base load for Lake Erie, which is an estimate of the expected phosphorus load to the lake if the phosphorus concentrations in all municipal wastewater discharges were at 1.0 mg/l and if average conditions existed for land runoff, atmospheric, and upstream inputs, is established at 12,856 mt/yr (International Joint Commission 1981). The Lake Erie Wastewater Management Study (Yaksich 1982), however, recommends that a new base-year load of 16,455 mt/yr be accepted based on 1978-1980 tributary loading data (see Land Use Activities section).

In the nearshore regions of Lake Erie, several areas were found not to be in compliance with Water Quality Agreement objectives. Table 18 provides a list of violations for specific areas of concern. The following general problem regions have ben identified:

1. Ohio and Michigan nearshore regions of western Lake Erie, particularly in the vicinity of major harbors, had persistent violations of DO, ammonia, fecal coliforms, total phosphorus, and several trace metals.

2. Ohio and Pennsylvania nearshore regions of central Lake Erie, particularly at the major river mouths, have persistent violations of conductivity and the three trace metals, cadmium, copper, and zinc.

3. Pennsylvania and New York nearshore regions of eastern Lake Erie were relatively free of violations except for Erie Harbor where fecal coliform numbers were high in late summer.

4. Ontario nearshore regions throughout the lake were generally in compliance with only minor violations at tributaries and ports.

Emerging problems are difficult to assess, particularly with lack of comprehensive data on the nature of toxic organic compounds in the water, sediment and biota of Lake Erie. Problems associated with toxic compounds are most likely to emerge in the

TABLE 18

VIOLATIONS OF LAKE ERIE WATER QUALITY OBJECTIVES

LOCATION	INFREQUENT VIOLATIONS	FREQUENT VIOLATIONS
Western Basin Nearshore		
1. Pointe Mouillee to Stony Point, Michigan	ammonia, cadmium copper, zinc, mercury	DO, pH, conductivity, fecal coliforms, iron, manganese, nickel
2. River Raisin Mouth/ Monroe, Michigan	DO, copper, zinc, mercury	pH, conductivity, iron, nickel
3. Maumee River Mouth/Maumee Bay, Michigan and Ohio	cadmium, copper, zinc, mercury	DO, pH, ammonia, conductivity, total phosphorus, fecal coliforms, iron, magnanese, nickel
4. Toussaint River Mouth/ Locust Point, Ohio	cadmium, copper, nickel, zinc	conductivity, iron
5. Portage River Mouth/ Port Clinton, Ohio	pH, conductivity, chromium, zinc	fecal coliforms, iron, nickel
6. Sandusky River Mouth/ Sandusky Bay, Ohio	DO, copper, mercury	pH, conductivity, fecal coliforms, iron, nickel
7. Bar Point to Leamington, Ohio	pH, total phosphorus	

TABLE 18 (CONTINUED)

LOCATION	INFREQUENT VIOLATIONS	FREQUENT VIOLATIONS
Western Basin Main Lake		
1. Entire Basin, U.S. Canada	DO, pH, total phosphorus, zinc	iron
Central Basin Nearshore		
1. Huron River Mouth/ Huron, Ohio	pH, copper, zinc	DO, conductivity, fecal coliforms, iron, nickel
2. Black River Mouth/ Lorain, Ohio	DO, iron, nickel, zinc, phenols, ammonia	conductivity, cadmium, copper
3. Rocky River Mouth to Cuyahoga River Mouth/ Cleveland, Ohio	DO, conductivity, fecal coliforms, phenols, ammonia	cadmium, copper, iron, nickel, zinc
4. Grand River Mouth/ Fairport, Ohio	conductivity, iron, nickel	cadmium, copper, zinc
5. Ashtabula River Mouth/ Ashtabula, Ohio	DO, conductivity, iron	cadmium, copper, zinc
6. Conneaut Creek Mouth/ Conneaut, Ohio	DO, conductivity, cadmium copper, nickel, zinc	
7. Wheatley to Point Burwell, Ontario	DO, pH, total phosphorus, ammonia, phenols, fecal coliforms	

TABLE 18 (CONTINUED)

LOCATION	INFREQUENT VIOLATIONS	FREQUENT VIOLATIONS
Central Basin Main Lake		
1. Entire Basin, U.S. and Canada	pH, total phosphorus, zinc	DO, iron
Eastern Basin Nearshore		
1. Presque Isle Bay/ Erie, Pennsylvania	DO, conductivity, fecal coliforms, cadmium, copper, nickel, zinc	
2. Barcelona to Buffalo, New York	DO, conductivity, cadmium, copper, nickel	
3. Long Point Bay to Fort Erie, Ontario	pH, conductivity, total phosphorus, cadmium, silver	iron, zinc
Eastern Basin Main Lake		
1. Entire Basin, U.S. and Canada	pH, total phosphorus, zinc	iron

nearshore waters, especially harbors such as Monroe, Toledo, Lorain, Cleveland, Ashtabula, Erie, and Buffalo, where preliminary indications have been observed.

Another problem of a totally different nature may also present itself by the end of the decade. Lake Erie sport fish production is at an all-time high. This production, primarily in the western basin and along the south shore of the central basin, is nurtured by high nutrient concentrations and associated primary/secondary productivity. As phosphorus controls become more and more effective in limiting algal production, which is needed to reduce the anoxic region of the central basin hypolimnion, the food for such important fish species as walleye (<u>Stizostedion</u> <u>vitreum</u> <u>vitreum</u>) and yellow perch (<u>Perca flavescens</u>) may be eroded. As the 1980s proceed, it will become increasingly important to consider the balance between western basin fish production and central basin hypolimnion oxygen content.

RECOMMENDATIONS

During the 1970s Lake Erie reached stable conditions and in the early 1980s it has shown signs of improvement: nutrient loadings are declining, phosphorus concentrations in the lake are dropping, some sources of contamination by toxic substances are being checked, levels of contaminants in lake sediments and biota are subsiding, "clean water" forms of plankton and benthos are showing modest signs of recovery, and fish populations are rebounding. However, cause and effect relationships of all of these changes are not obvious, most of the improvements have been small, and for many parameters, conclusive trends have yet to be established. Nonetheless, evidence for improvement is beginning to mount and it is becoming obvious to scientists, fishermen and shoreline dwellers alike that Lake Erie is recovering. The extent of future improvements will depend on continuing efforts to control loading of nutrients and toxic substances to the lake, particularly those associated with industrial and agricultural practices. Surveillance of Lake Erie water, biota, and sediment conditions must continue if we are to establish clear relationships between remedial actions and lake quality.

The 1978-1979 Lake Erie Intensive Study has provided the most comprehensive set of data available for Lake Erie. However, many questions remain unanswered, particularly in reference to the loading of toxic substances to the lake and its ecological impact. Many cause and effect relationships in the lake are poorly understood as are effects of specific remedial actions. To improve our understanding of this complex system and to eventually improve the quality of Lake Erie the following surveillance activities, remedial actions, evaluations, and special studies are recommended:

<u>Surveillance</u>

1. A comprehensive surveillance for Lake Erie should be conducted on an annual basis and should contain the following components: a) main lake, b) nearshore areas of concern, c) water intakes, d) tributaries and connecting channels, e) point sources, f) atmospheric deposition, g) beaches, and h) bio-monitoring.

2. Main lake surveillance should be conducted in spring, summer and fall to determine a) the seasonal concentration and quantity of nutrients in each basin, b) the oxygen depletion rate and area of anoxia in the central basin, and c) seasonal biomass, including Cladophora.

3. Nearshore areas of concern should be stressed in an annual monitoring program owing to the fact that these areas are the most highly impacted (or potentially impacted) areas within the lake, particularly in terms of toxic substances.

4. Water intake monitoring should be integrated into the nearshore surveillance effort at areas of concern.

5. Because of the increasing importance of diffuse source loading to Lake Erie, surveillance of major tributaries and connecting channels should be expanded to include both periodic and event sampling (i.e. Detroit, Raisin, Maumee, Sandusky, Black, Rocky, Cuyahoga, Grand of Ohio, Ashtabula, Buffalo, Grand of Ontario and Niagara rivers).

6. Point sources, particularly wastewater treatment plants, should be monitored routinely to ascertain compliance with Water Quality Agreement objectives.

7. Atmospheric deposition (wet and dry) monitoring should be continued within the Lake Erie drainage basin.

8. Because of the obvious public health hazards, Lake Erie bathing beaches should be monitored for bacterial contamination throughout the summer season.

9. Bio-monitoring programs should be expanded to detect a wider array of toxic substances in Lake Erie biota (e.g. young-of-the-year spottail shiners and Cladophora).

10. Future intensive studies should not be necessary if a flexible annual surveillance plan is adopted which is reviewed and modified each year to address continuing and emerging problems.

Remedial Actions

1. The agricultural community should be encouraged to adopt conservation tillage or no-tillage practices on all suitable soils within the Lake Erie drainage basin.

2. As specified in the Water Quality Agreement of 1978, actions should be taken to ensure that all municipal wastewater treatment plants within the Lake Erie drainage basin which discharge in excess of 1 mgd are operated so that total phosphorus concentrations in their effluents do not exceed a maximum concentration of 1.0 mg/l.

3. States not presently limiting the amount of phosphorus in household detergents should enact legislation which permits no more than 0.5% P.

4. Special efforts should be undertaken to identify and control sources of toxic substances, including in situ toxicant sources from sediments.

5. Education programs should be developed for specific land use activities (i.e. agri-business, urban development, industry, recreation) to foster pollution control.

6. If the U.S. Army Corps of Engineers calculations for base load are correct, then there needs to be an intensified effort to identify cost effective means of reducing phosphorus loads, beyond the present goals.

Evaluation

1. Future evaluations of water quality violations should be related to impaired use of the lake (e.g. beaches, water supply, fishery)

2. The Lake Erie surveillance plan should be reviewed and evaluated annually to ascertain if it is providing the necessary information for designing effective management actions.

3. Before new surveillance plans are developed, a careful evaluation of past data and statistical techniques should be undertaken to more clearly understand apparent trends, or lack thereof, in lake conditions and biota.

4. Once new surveillance programs are implemented they should be reviewed annually to determine their effectiveness in evaluating remedial programs.

Special Studies

1. Studies should be continued to determine the ecological impact to Lake Erie of herbicide and insecticide runoff from conservation tillage cropland.

2. Studies should be continued to determine the relative availability of the various forms of phosphorus for biological productivity.

3. Studies should be initiated to determine the role of hypolimnetic phosphorus regeneration and wave resuspension as a mechanism for internal loading.

In order for any of these recommendations to be fully effective, it is important that an international body (i.e. International Joint Commission) assume a leadership role in planning, organizing, and securing funds to implement those actions which are deemed necessary to enhance the quality of the Great Lakes. A greater degree of cooperation is required among federal and state agencies, research institutions and resource users to effect the recovery of Lake Erie. The International Joint Commission has a key role in fostering such cooperation.

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APPENDIX A

LAKE ERIE INTENSIVE STUDY REPORTS
PREPARED BY THE LAKE ERIE TECHNICAL ASSESSMENT TEAM

TAT Cont. No.	CLEAR Tech. Rept. No.	Report Title	Principal Author(s)
1.	226	Introduction, Methods and Summary	C.E. Herdendorf
2.	227	Data Compatability Analysis	P. Richards
3.	228	Main Lake Water Quality	D. Rathke L. Fay
4.	229	Nearshore Water Quality	L. Fay D. Rathke
5.	230	Nearshore Nutrient Distribution - Detroit River to Huron, Ohio	J. Letterhos
6.	231	Trace Metals in Main Lake and Nearshore Waters	C.L. Cooper S. Hessler
7.	232	Microbiology in Main Lake and Nearshore Waters	C.L. Cooper C. Kimerline
8.	233	Main Lake and Nearshore Water Quality Problem Areas	C.L. Cooper A. Rush W. Snyder
9.	234	Water Quality Violations - Detroit River to Huron, Ohio	C.E. Herdendorf L. Fay
10.	235	Synoptic Mapping of Water Quality - Western Basin	Y. Hamdy C.E. Herdendorf
11.	236	Water Quality Index Evaluation	J.J. Mizera C.E. Herdendorf
12.	237	Cluster Analysis of Nearshore Water Masses	C.E. Herdendorf J.J. Mizera

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13.	238	Nearshore Phytoplankton - Detroit River to Huron, Ohio	D.Z. Fisher D. Rathke
14.	239	Cladophora Surveillance Program - Western Basin	R. Lorenz C.E. Herdendorf
15.	240	Fisheries Status and Response to Water Quality	M.D. Barnes
16.	241	Toxic Organic Contaminants in Fish	B. Burby M.D. Barnes C.E. Herdendorf
17.	242	Nearshore Benthic Macroinvertebrates - Detroit River to Huron, Ohio	G. Keeler
18.	243	Macroinvertebrates in Main Lake and Nearshore Sediments	P.E. Steane C.L. Cooper
19.	244	Annotated Bibliography of Lake Erie Benthic Macroinvertebrates	G. Keeler
20.	245	Main Lake Sediment Chemistry	N. Carlson J.J. Mizera
21.	246	Sediment Oxygen Demand	W. Davis L. Fay C.E. Herdendorf
22.	247	Historical Water Quality Trends - Cleveland, Ohio	P. Richards
23.	248	Nearshore Water Quality Trends	A. Rush C.L. Cooper
24.	249	Main Lake Water Quality Trends	C.E. Herdendorf L. Fay
25.	250	Nutrient Loading to Lake Erie and Its Effect on Lake Biota	K-P Chen R. Sykes
26.	260	Lake Erie Intensive Study 1978-1979 -- Final Report	D. Rathke et al.
27.	261	Lake Erie Intensive Study 1978-1979 -- Management Report	C.E. Herdendorf

APPENDIX B

LAKE ERIE INTENSIVE STUDY REPORTS CONTRIBUTED TO THE LAKE ERIE TECHNICAL ASSESSMENT TEAM

A.	Tributary Component	Contributor	Date
1.	Monthly monitoring data (computer print-out) for Clinton, Rouge, Ecorse, Huron, Raisin Rivers, 1978-1979	Vitelhic, MDNR	June 1981
2.	Monthly monitoring data of Erie County, Pa. tributaries: Walnut, Elk, Sixteen-mile (tabular data)	Wellington, ECDH	Dec. 1980
3.	Summary of phosphorus loading data for 1978 collected by IJC Regional Office (computer print-out)	Haffner, IJC-Windsor	June 1980
4.	Toledo Area River and Stream Water Quality Data Report, 1968-1974 (March, 1976)	Russell, TPCA	July 1980
5.	Water quality data collected by the Toledo Pollution Control Agency at the C&O docks at the mouth of the Maumee River, 1975-1981 (bench sheets)	Russell, TPCA	Feb. 1981
6.	Estimation of tributary total phosphorus load into Lake Erie, evaluation of applicable models	Kuo-pin Chen, OSU-TAT	Dec. 1980
7.	Periodic tributary monitoring data (computer print-out) of Lake Erie tributary surveillance conducted by the New York State Dept. of Environmental Conservation	Maylath, NYDEC	Dec. 1980
8.	Summary of total phosphorus loadings for the water years 1970 to 1977 for Canadian streams draining into Lake Erie	Terry, MOE	Feb. 1981

9.	Total phosphorus loadings for the water years 1978 and 1979 for the Canadian streams draining into Lake Erie	Terry, MOE	Jan. 1981
10.	On Phosphorus and its availability in total loading into Lake Erie, 1970-1980	Kuo-pin Chen, OSU-TAT	May 1981

B. <u>Point Source Component</u>

1.	Summary of the phosphorus loading data collected by the IJC Regional Office for 1978	Haffner, IJC-Windsor	June 1980

C. <u>Atmospheric Component</u>

1.	Preliminary outline draft: final report for 1979-1980: An experimental study of Lake Loading by Air Pollution Transport and Dry Deposition	Sievering, et al. Governors State Univ.	Sept. 1982
2.	Summary of Great Lakes weather and ice conditions, winter 1978-1979. Tech. Mem. ERL GLERL-31	NOAA, GLERL	Aug. 1980

D. <u>Connecting Channels Component</u>

1.	Water Year 1980-Detroit River (6 page rept.)	MDNR	June 1981
2.	Water quality assessment of the Thames River mouth, Lake St. Clair, 1975.	Hamdy, Kinkead, Griffiths, MOE	June 1980
3.	Great Lakes water quality data summary, Detroit River 1976	MOE	June 1980
4.	Great Lakes water quality data summary, St. Clair River 1976	MOE	June 1980

5.	St. Clair River organics study, waste dispersion	Hamdy and Kinkead, MOE	June 1980
6.	St. Clair River organics study. The detection of mutagenic activity; screening of twenty-three compounds of industrial origin	Rokosh and Lovasz, MOE	June 1980
7.	St. Clair River organics study. Biological surveys 1968 and 1977	MOE	June 1980

E. <u>Nearshore Intensive Surveillance Component</u>

1.	Investigation of water quality in the Leamington area of western lake Erie, 1973-1976	Hamdy and Kinkead MOE	June 1980
2.	Recent changes in the phyto-plankton of Lakes Erie and Ontario	Nicholls, MOE	June 1980
3.	Phytoplankton studies in the Nanticoke area of Lake Erie, 1969-1978	Hopkins and Lea, MOE	June 1980
4.	Water movements in the Nanticoke region of Lake Erie, 1976. Ibid., 1978	Kohli, MOE	June 1980
5.	Nanticoke Water Chemistry 1975, Ibid. 1976	Polak, MOE	June 1980
6.	Nanticoke Aquatic Environment, 1967-1974	Palmer and Polak, OMOE	June 1980
7.	Declines in the nearshore phyto-plankton of Lake Erie's western basin since 1971	Nicholls, et al. MOE	June 1980
8.	An assessment of water quality conditions Wheatley Harbour, Lake Erie 1979	Hamdy and Ross, MOE	Sept. 1980
9.	An assessment of the bottom fauna and sediments of the western basin of Lake Erie, 1979	MOE	May 1981

10.	Biological status in nearshore zone of the south shore of Lake Erie between Vermilion and Ashtabula, Ohio: Preliminary Report	Krieger et al. Heidelberg College	Feb. 1979
11.	Water quality and some aspects of chemical limnology in the near-shore zone of the south shore of Lake Erie between Vermilion and Ashtabula, Ohio: preliminary report	Richards, Heidelberg College	Feb. 1979
12.	Limnological surveillance of the nearshore zone of Lake Erie in central and eastern Ohio. Preliminary report. Part I: Chemical Limnology	Richards, Heidelberg College	Jan. 1980
13.	Chemical limnology in the near-shore zone of Lake Erie between Vermilion, Ohio and Ashtabula, Ohio, 1978-1979: Data Summary and Preliminary Interpretations and Appendices	Richards, Heidelberg College	Feb. 1981
14.	Historical trends in water chemistry in the U.S. Nearshore Zone, central basin, Lake Erie	Richards, Heidelberg College-TAT	Nov. 1981
15.	Data Compatability Analyses - Lake Erie International Surveillance Plan	Richards, Heidelberg College-TAT	Nov. 1981
16.	Environmental status of the southern nearshore zone of the central basin of Lake Erie in 1978 and 1979 as indicated by the benthic macroinvertebrates	Krieger, Heidelberg College	June 1981
17.	The crustacean zooplankton of the southern nearshore zone of the central basin of Lake Erie in 1978 and 1979: Indications of trophic status	Krieger, Heidelberg College	June 1981
18.	Composition and abundance of phytoplankton of the central basin of Lake Erie during 1978-1979. Lake Erie Nearshore study	Kline, Heidelberg College	Oct. 1981

19.	Bacterial water quality of the southern nearshore zone of Lake Erie in 1978 and 1979	Stanford, Heidelberg College	Sept. 1981
20.	A preliminary summary of the 1978 nearshore monitoring program for eastern Lake Erie	SUNY-Buffalo	March 1979
21.	Lake Erie nearshore monitoring program, Conneaut, Ohio to Buffalo, New York, Part I, 1978	SUNY-Buffalo	April 1981
22.	Cruise means data for 1978 and 1979 nearshore monitoring program for eastern Lake Erie (computer print-out)	SUNY-Buffalo	Nov. 1981
23.	Western Lake Erie nearshore intensive study 1978-1979: Microbiology	Diamond et al. OSU-CLEAR	Dec. 1980
24.	Western Lake Erie nearshore intensive study 1978-1979: Nearshore water quality problem areas	Herdendorf and Fay, OSU-CLEAR	Dec. 1980

F. Water Intake Component

I.	Water intake monitoring data collected during 1978-1979 by the Erie County (Pa.) Dept. of Health (WQN Sta. 601)	Wellington, ECDH	Dec. 1980

G. Beach Monitoring Component

I.	Comprehensive summer beach surveillance data collected by the Erie County (Pa.) Dept. of Health	Wellington, ECDH	Dec. 1980
2.	Lake Erie beach monitoring reports 1978-81	Witt, USEPA/GLNPO	Sept. 1982

H. Cladophora Component

1.	Cladopohora monitoring - central and eastern basins	Millner et al. SUNY-Buffalo	Dec. 1979

I. Main Lake Component

1.	Workshop on the analysis and reporting of Erie 79 and Erie 80 experiments (Stage 1)	Boyce, CCIW	Nov. 1980
2.	Report on summer phosphorus and oxygen for Lake Erie - 1970, 1977 and 1978	Rosa, CCIW	April 1979
3.	Lake Erie water chemistry and sediment data 1978-1979	Rockwell, USEPA/GLNPO	Dec. 1980
4.	Lake Erie dissolved substances report 1967-1980	Rockwell, USEPA/GLNPO	April 1982
5.	Lake Erie phytoplankton report 1978-1979, preliminary results	DeVault, USEPA/GLNPO	May 1982

J. Fish Contaminants Component

1.	Organic chemical residues in Region V watersheds (data rept.)	Veith and Kuehl, USEPA/ Duluth ERL	June 1980
2.	Organochlorine contaminant concentrations and uptake rates in fishes in Lake Erie tributary mouths (abst. and data summary)	Herdendorf, Barnes, Burby, OSU-TAT	Dec. 1980
3.	Laboratory report. Residues of polychlorinated dibenzo-p-dioxins and dibenzofuransin Great Lakes fish	Stallings, et al., USF & WS	July 1981
4.	Trends in the mercury content of western Lake Erie fish and sediment, 1970-1977	Kinkead and Hamdy, OMOE	June 1980

K. Wildlife Contaminants Component

No reports to TAT

L. Radioactivity Component

1.	1977-1979 environmental radiological monitoring for the Davis-Besse Nuclear Power Station at Locust Point and Lake Erie	Toledo Edison Co.	Aug. 1980

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15. SUPPLEMENTARY NOTES

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16. ABSTRACT

This report is to highlight the findings and conclusions of the 1978-1979 Lake Erie Intensive Study by placing them in perspective with earlier investigations and subsequent monitoring data from 1980 to 1982, where available. The primary purpose of this report is to provide management information in the form of a review of the lake's status and its trends and in the form of recommendations to ensure continued improvements in the quality of its waters and biota. Lake Erie has experienced several decades of accelerated eutrophication and toxic substances contamination. During the latter part of the 1960s remedial actions were planned and by the latter part of the 1970s, many of the plans were at least partially implemented.

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